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BORN JUNE 27, 1817; DIED MARCH 24, 1889.

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1889.

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Cowper, Edward
Crease, John Frederick, Lieut.-Col., C.B.
Crofton, Edward
Cross, William
Crowder, Captain T. W.
Curme, C. T., Vice-Admiral, R N.
Custance, Reginald, Capt. R.N. (Assoc. Mem. Council)

Da Costa, S. J.
Darling, John
Dawes, E. S.
De Cuverville, Le Contre, Admiral I. de Cavelier, French Navy
De Horsey, Algernon F. R., Vice-Admiral, R.N.
Dempster, John
Denny, John McA.
Dent, Admiral C. C.
Dixon, James
Donkin, Richard Sims, M.P.
Doux, Richard Le
Du Guengo, Lieut. Rocher
Dudgeon, Alexander John
Dudgeon, William Leigh
Duncan, George (Assoc. Mem. Council)

Eckart, William R., C.E.
Edinburgh, H.R.H. the Duke of, K.G., Kt., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., Admiral (Vice-President)
Eidlitz, Leopold, jun.
Ellis, W. H. M.
Elms, Charles
Evans, R. D., Commander, United States Navy
Evans, David
Evans, Frederick E.
Eyton, T. W.

Fanshawe, Sir Edward Gennys, K.C.B., Admiral
Fassella, Cavaliere Felice
Fenwick, Fenwick J.
FitzGerald, C. C. P., Captain, R.N.
Fowler, Sir John, K.C.M.G., F.R.S.
Fox, Samson
Fraissinet, Alfred
Frear, Hugo P.
Fremantle, Rear-Admiral The Hon. E. R., C.B.
Froude, R. E. (Assoc. Mem. Council)

Gatewood, Richard
Gatow, Bernard
Gavin, John
Gervais, A., Admiral, French Navy
Gilchrist, Percy C.
Gisborne, John S.
Goodridge, Capt. John J. L.
Gough, Kedgwin E. K.
Graves, W. T.
Gray, Thomas, C.B.
Grenfell, H. H., Capt. R.N.
Griscom, C. A.

Hamilton, The Right Hon. Lord George, M.P. (Vice-President)
Harfield, William Horatio
Harris, John Henry
Hartmann, Wilhelm
Hay, James M.
Hay, The Right Hon. Lord John, G.C.B., Admiral (Vice-President)
Hay, The Right Hon. Sir John Dalrymple, Bart., K.C.B., D.C.L., F.R.S., Admiral (Vice-President)
Hayward, William
Healey, Edward C.
Hendersen, George T.
Henderson, Thomas
Hide, T. C.
Hill, Arnold F.
Hill, E. J.
Hill, E. S., Colonel, C.B., M.P.
Hill, W. Becket
Hodges, Petronius
Hodgkinson, Capt. George
Hogarth, A. P.
Holland, Arthur, M.A.
Holland, S. C., Captain, R.N.
Houldsworth, William
Hovgaard, Lieut. W. (Royal Danish Navy)
Howard, J. William
Howell, J. Bennett
Holzapfel, A. C. A.
Hughes, John
Hurndall, W. F.
Hutchinson, Walter E.

Ihlen, Nils, Admiral, Norwegian Royal Navy
Ismay, Thomas H.
Ivanoff, N., Lieut.-Col., Russian Imperial Navy

Jacobsen, Waldemar
Jamieson, John D.
Jaques, Lieut. W. H., U.S.N.
Jarman, Stephen, R.N.R.
Jones, Major Charles
Jones, Sir Lewis T., G.C.B., Admiral

Kemp, Dixon (Assoc. Mem. Council)
Kennedy, Donald, J.P.
Kirkaldy, John
Knott, James
Knudson, Gunnar
Korshicoff, Nicolas, General, Russian Imperial Navy

Labrano, F., Captain, Italian Royal Navy
Lagane, Amable
Lagerwall, J. M., Captain, Royal Swedish Navy
Laidley, R. W.
Lautrup, Christian
Laws, George A.
Lee, John D.
Lewes, Vivian B.
Likhatchof, J., Vice-Admiral, Imperial Russian Navy
Lilburn, James
Linnard, Joseph Hamilton
Lister, W. N., Lieut., R.N.R.
Little, Henry W.
Littleboy, C. W.
Long, A. E.
Long, Samuel, Captain, R.N.
Lund, William
Lüning, J. G.
Lyster, G. Fosbery

MacDonnell, Alexander
MacDougall, Dugald
MacIlwraith, A.
MacIver, C.
MacIver, H.
Mackenzie, James
Mackenzie, Landseer
Mainwaring, Lieut.-General R. R.
Marr, James
Marshall, Frank T.
Martin, Edward
Martin, Edwin
Martin, Sir Wm. F., Bart., K.C.B. Admiral
Martin, W. Tyson
Massey, W. A.
Mayne, Richard C., Admiral, C.B., M.P.

McGregor, J.
McHardy, Wallace Bruce, Commander, R.N.
McKirdy, John
Medhurst, John T.
Meyer, John
Milburn, J. D.
Milburn, William, jun.
Miller, Gordon
Milne, Sir Alexander, Bart., G.C.B., Admiral of the Fleet (Vice-President)
Moore, W. J. P.
Moore, William W.
Morrison, James

Napier, James
Nava y Caveda, His Excellency General H., Spanish Royal Navy
Neal, William George
Neilson, John
Neilson, Walter M., Colonel
Newey, Samuel C.
Newman, A. R.
Nicolson, Sir Frederick W. E., Bart., C.B., Admiral (Vice-President)
Noel, G. H., Captain, R.N. (Assoc. Mem. Council)
Northbrook, The Right Hon. the Earl, G.C.S.I. (Vice-President)
Norton, Harold Percival

Orlando, Paolo

Page, John
Palmer, William
Panton, Charles E.
Parsons, P. R.
Pascoe, J. R.
Pearse, Mountjoy
Perkins, James
Petree, James
Pile, Charles H.
Poretchkin, Theodore, Lieut., I.R.N.
Potter, John
Pover, W. T.
Price, Arthur, R.N.

Raalte, J. van
Ramsden, Sir James, Kt. (Vice-President)
Ratliffe, G.
Ravensworth, The Right Hon. the Earl of (President)
Rawson, Robert, Hon. Mem. Manchester Literary and Philosophical Society
Rendel, Hamilton Owen
Rennie, Keith T.
Rice, J. M., United States Navy
Ridley, John H.
Riley, James
Ritson, Francis
Robinson, Sir R. Spencer, K.C.B., F.R.S., Admiral (Vice-President)
Robson, George
Rogerson, John
Ropner, R., jun.
Rose, John B.
Rothe, H. P., Commodore, Danish Royal Navy
Rowan, David
Rowley, Charles J., Rear-Admiral

Samuelson, Sir Bernhard, Bart., C.B., M.P.
Sandham, Henry
Sandstrom, Theodore C. A., Com., Royal Swedish Navy
Saunders, James Ebenezer
Schmeman, Alexander
Schüler, F.
Schunk, Theodore
Scott, Colin W.
Scott, Ernest
Scott, George J.
Scott, William
Serena, Arthur
Shankland, Robert
Smith, G. Fereday, M.A., J.P.
Smith, John
Smith, The Right Hon. W. H., M.P. (Vice-President)
Smyth-Pigott, J. H.
Spence, James
Spencer, John W.
Stewart, Walter J. L.
Stuart, Milton
Stumore, Frederick
Sudeley, The Right Hon. Lord
Swinburne, Thos. A., Captain, R.N.

Tapscott, G. L.
Tatham, Hollings
Taylor, George W.
Taylor, J. M. H.
Temperley, Joseph
Terry, S. H.
Thomas, Philip A.
Thompson, Stephen
Thomson, Andrew
Thurston, Robert H., Professor
Tindall, William H. (Vice-President)
Tough, R. T.
Tryon, George, Rear-Admiral, C.B. R.N.

Varley, John
Vavasseur, Josiah
Vaz, J. M. P. da F., Captain, Portuguese Royal Navy

Waddilove, Charles L. D., Vice-Admiral, R.N.
Watson, George C.
Watson, H. Burnett
Watson, Henry James
Watson, W.
Watson, William

Watts, Edmund H.
Webb, F. W.
Webb, J. Beavor
Westmacott, Percy G. B.
Williams, Samuel
Williamson, J.
Williamson, R. H.
Wilmot, S. Eardley, Captain, R.N.
Wingfield, G. J., Lieut., R.N.
Wise, William Lloyd
Woodall, J. W.
Woodward, Joseph J.
Woolfe, J. S.

Ziffer, J. H.

OBJECTS OF THE INSTITUTION.

The objects of the Institution of Naval Architects—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads :—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our Navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. The Institution of Naval Architects shall consist of four classes, viz., Members, Associates Honorary Members, and Honorary Associates.

2. *Members.*—The class of Members shall consist exclusively of Naval Architects, and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

7. A General Meeting of the Members and Associates of the Institution shall be held annually before Easter in each year; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the election of Associate Members of Council, the Treasurer, and the Auditors.

9. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

10. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

11. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present to preside.

12. The Chairman at any Meeting of the Council of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

13. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

14. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

15. *Members of Council.*—Members only shall be eligible for Election as Members of Council at the Annual General Meeting.

16. *Associate Members of Council.*—Associates only shall be eligible for Election as Associate Members of Council at the Annual General Meeting.

17. The Direction and Management ot the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

18. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of the Council shall form a *quorum.*

19. The Council may appoint Committees to report to them upon special subjects.

20. All questions shall be decided in the Council by vote ; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding meeting of the Council.

21. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and, after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

22. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

23. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

24. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council and are still Members of the Institution, shall be eligible for election as Treasurer.

25. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

26. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

27. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

29. In each year six Ordinary and two Associate Members of Council shall retire, unless before the date of drawing up the Balloting Lists for the election of the Council any Members of the Council shall have died or resigned, in which case only so many members shall retire as shall be necessary in order to make up the number to six Ordinary and two Associate Members of Council, subject always to the provisions of Rule 31. The Members who shall retire in each year shall be those who have served longest on the Council from the date of the last election, and in the event of there being several Members who have served an equal time on the Council, the order of retirement amongst these shall be alphabetical. The retiring Members shall be eligible for re-election.

30. In January of each year the Council shall meet and prepare Lists for the election of the Council for the ensuing year. These Lists shall be as follow, namely :—

1*st.* A List of the names of the President, Vice-Presidents, and Treasurer for the ensuing year to be submitted at the Annual General Meeting, for their election in a body.

2*nd.* Lists for the election of the Ordinary Members and Associate Members of Council.

31. No addition shall be made to the total number of Ordinary Members of the Council until, by death or resignation, their numbers shall have been reduced below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. And no addition shall be made to the Associate Members of Council until, by death or resignation, their numbers shall have been reduced below eight, after which their numbers shall be raised to and preserved at eight, always exclusive of the President, Vice-Presidents, and Treasurer.

32. At the date of issuing the Syllabus of the Annual General Meetings in each year, the Lists proposed by the Council for the election of Members to fill the vacancies in the Ordinary Council for the ensuing year shall be printed, and sent to all Members to serve as Balloting Lists. These Lists shall contain, first, the names of the retiring Ordinary Members of Council at the time of the preparation of the Balloting List, together with as many new names of Members of the Institution as shall be needed to bring the number up to twice the number of vacancies, and the whole of these names shall be printed in alphabetical order. Secondly, the names of the retiring Associate Members of Council at the time of the preparation of the Balloting List, together with as many new names of Associates of the Institution as shall be needed to bring

the number up to twice the number of vacancies, and these names also shall be printed in alphabetical order. From these Lists the vacancies in the Council shall be filled up. Every Member shall be at liberty to vote for as many names on each of the Lists as there are vacancies to be filled, but not for more.

33. A similar Balloting List (in which, however, the names of the Ordinary Members of Council proposed for election shall not be included) shall be printed and sent to all Associates of the Institution, to serve as a Balloting List for Associates, from which the voting for Associate Members of Council shall be taken. Every Associate shall be at liberty to vote for as many names on that List as there are vacancies to be filled, but not for more.

34. The Balloting Lists may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be personally presented by the Members and Associates at the opening of the Annual General Meeting.

35. At the opening of the Annual General Meeting the order of business shall be :—

(1) To read and consider the Reports of the Council and Treasurer.

(2) To read the List of Officers and Nomination for Council for the ensuing year, proposed by the Council.

(3) The Chairman shall next put to the Meeting the List containing the names of the President, Vice-Presidents, and Treasurer for election for the ensuing year.

(4) The Chairman shall then nominate two Scrutineers (of whom one only shall be a Member of the existing or proposed Council), and shall hand to them the Ballot Boxes containing the Voting Papers for the Ordinary Members of Council and Associate Members of Council ; and

(5) The Scrutineers shall receive all Ballot Papers which may have reached the Secretary, and all others which may be presented by Members or Associates at the Meeting. The Scrutineers shall then retire and verify the Lists, and count the votes ; and shall, not later than the following day, report to the Chairman the names which have obtained the greatest number of votes, subject to the conditions of the Ballot. The Chairman shall then read the List presented by the Scrutineers, and shall declare the gentlemen named in the List to be duly elected, provided always that the List does not contain more names than there are vacancies to be filled. If, in consequence of two or more of the candidates receiving an equal number of votes, the List shall contain more names than there are vacancies, the Council shall, at their next meeting, decide which of these candidates shall be elected.

(6) After the Ballot shall have been taken, and the Scrutineers have retired, the Meeting will proceed to the other business before it.

36. The new Council and Officers shall take office immediately after the close of the Annual General Meeting.

DESIGNATION OF MEMBERS AND ASSOCIATES.

37. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, viz., M.I.N.A. ; Assoc. I.N.A. ; Hon. Mem. I.N.A. ; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

38. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulations :—

He shall submit to the Council a statement showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer conversant with Naval Architecture, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

39. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement), at an Ordinary Meeting of the Institution, for them to vote upon, the voting to be by ballot, should a ballot be demanded.

40. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon, the voting to be by ballot, should a ballot be demanded.

41. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

42. Each Member and Associate shall pay an Entrance Fee of two guineas, and an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

43. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

44. No person's name shall be entered on the Roll as Member or Associate of the Institution nor possess the privileges of Membership (except it be on the honorary list) until he shall have paid his first subscription or the life composition, and if the payment be delayed for more than twelve months from the date of his election, the same shall be void unless the Council otherwise direct.

45. The Secretary shall at the close of every year notify to all Members and Associates whose subscription for that year shall not have been paid, that it will be his duty to report accordingly to the Council, and he shall at the same time furnish the person whose subscription is in arrear with copies of this and the two following Rules.

46. The Secretary shall before Easter in every year lay before the Council a list of all Members and Associates whose subscriptions for the two previous years shall be still unpaid, and unless the Council shall otherwise direct, the names of those in arrear shall be expunged from the Roll of Members and Associates, and shall not be replaced without re-election in due form. Provided always that the Council shall at any time

within two years therefrom have power to dispense with such re-election, and to restore the name to the Roll upon payment of all subscriptions then due, and upon cause being shown to the satisfaction of the Council why such subscriptions were not previously paid.

47. Nothing herein contained shall prejudice the right of the Institution to the legal recovering of all arrears of subscriptions up to the date of striking the name off the Roll.

48. In case the Council shall be of opinion that any Member, who has been long distinguished in his professional career, from ill-health, advanced age, or other sufficient causes, should not be called upon to continue his annual subscription, they may remit it. Also they may remit any arrears which are due from an individual, or may accept a collection of books, or drawings, or models, or other such contribution as, in their opinion, under the circumstances of the case, may entitle the person to be enrolled as a Life Subscriber, or to enable him to resume his former rank in the Institution which may have been in abeyance from any particular causes. These cases must be considered and reported upon by a Sub-Committee named for the purpose.

49. In case the expulsion of any individual shall be judged expedient by ten or more Members, and they think fit to draw up and sign a proposal requiring such expulsion, the same being delivered to the Secretary shall be by him laid before the Council. If the Council, after due inquiry, do not find reason to concur in the proposal, no entry thereof shall be made in any Minutes, nor shall any public discussion thereon be permitted; but if the Council do find good reason for the proposed expulsion they shall direct the Secretary to address a letter to the person proposed to be expelled, advising him to withdraw from the Institution. If that advice be followed, no entry on the Minutes nor any public discussion on the subject shall be permitted; but if that advice be not followed, nor a satisfactory explanation given, the Council shall call a Special General Meeting of Members and Associates, for the purpose of deciding on the question of expulsion; and if two-thirds of the persons present at such Special General Meeting, providing the number so present be not less than thirty, vote that such individual be expelled, the Chairman of that Meeting shall declare such expulsion accordingly, and the Secretary shall communicate the same to the individual.

MEETINGS.

50. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

51. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

52. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

53. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a volume, provided a sufficient number remain on hand to supply the probable demand of New Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

54. Members and Associates are particularly requested to communicate to the Secretary any change of address.

PROCEEDINGS AT GLASGOW.

INSTITUTION OF NAVAL ARCHITECTS.

JULY 24, 25, AND 26, 1888.

PRELIMINARY PROCEEDINGS

AT THE HALL OF THE CORPORATION GALLERIES, SAUCHIEHALL STREET, GLASGOW,

TUESDAY, JULY 24, 1888.

The LORD PROVOST of Glasgow (Sir James King, LL.D.): My Lord and gentlemen, through the kindness of my colleagues and the members of the Reception Committee, I have been entrusted with the honour of welcoming this important Institution to Glasgow, and on the part of the Corporation of Glasgow, I wish to express the interest which we take in this meeting, recognising as we do that there is no industry on which the prosperity of our city depends more directly than on that of naval architecture. I am glad to have associated with me in the receiving of the Society, the Council of the Institution of Engineers and Shipbuilders in Scotland, and the Directors of the Clyde Steamship Owners' and Sailing Ship Owners' Associations. Through the preparations which have been made, I trust your meeting at this time will not be without interest and good fruit. I think that in Glasgow even our most advanced shipbuilders may have an opportunity of learning something from the visit of so many distinguished scientific men, and I daresay, on the other hand, even the most eminent of your number will find many objects of interest. I have no doubt also that after your severer labours you may find something to please and occupy your spare time in our Exhibition, and I hope to have the honour of receiving the Institution there on the afternoon of to-morrow. It would be unbecoming of me to occupy your valuable time in addressing you at any length, and I will now give place to your President, the Earl of Ravensworth.

[The Right Hon. the Earl of Ravensworth then took the chair.]

The PRESIDENT: My Lord Provost and gentlemen, it becomes my first duty, and my chief and most agreeable duty, to return on behalf of the Institution which I so very inadequately represent on this occasion, our united and heartfelt thanks for the gracious invitation of the engineers and shipbuilders of Scotland, and to you, my Lord Provost, for the invitation you have so graciously given us, and also to you all for the kind and hearty welcome which you have just accorded to us.

Now, my Lord Provost and gentlemen, I think it would strike everybody in this room—and I am glad to see so goodly an assembly—that there is a peculiarly appropriate significance in this invitation. The occasion and the place appear to me to be strictly in accord the one with the other, because when we remember that this is the centenary of steam navigation, and when we remember the great and leading part the shipbuilders, the engineers, and the mechanics of Glasgow from the outset took, and up to the present time have maintained, in that mighty development, it seems a gracious and an appropriate thing that we, the Institution of Naval Architects and Marine Engineers, should be invited by the Scotch Institution to join with them in a proper celebration of this interesting centenary upon the banks of the Clyde. There is one remarkable feature that has always struck me in the early stages of the development of that mighty industry, which has probably done more than any industry I could name to spread commerce and civilisation (and the two terms are almost synonymous) into the remotest parts of the known world—that the start was made in

Glasgow, and the feature to which I wish particularly to call attention is that from the outset we find Scottish lords and Scottish lairds going hand-in-hand with the engineer and shipbuilder and mechanic in that development. It was in 1788 that Mr. Miller and Mr. Symington constructed the first boat propelled by paddle and steam. That little boat was a pleasure boat. It was launched upon the waters of Dalswinton Loch, and I believe that under very favourable circumstances upon the smooth waters of an inland loch she attained the speed of five miles an hour. Well now, let us compare that with the performance of the *Etruria* last week, which came over from New York, and beat the record—interesting and magnificent as the record was—making the voyage in 6 days 1 hour and 50 minutes, an average (and that is one of the most interesting features of it) of 19·34 knots during the whole passage. I merely allude to this to compare the rate of five miles an hour upon the little inland loch with what is being done now on the ocean, as in doing so we obtain a certain gauge of the improvement effected in steam navigation during the centenary of which I have spoken. Well, we find that the same bold pioneers, Mr. Miller and Mr. Symington, in the following year built a larger boat. I do not know her name, but she attained two more miles an hour. I think she went seven miles an hour; but still she was a practical steamer. About ten years afterwards we find Mr. Symington, who was at the commencement of his career a young working engineer, and patronised only by Mr. Miller, obtained another patron, the first Lord Dundas, and built the *Charlotte Dundas*, which was constructed for the Forth and Clyde Canal Company.

Well, then, going on in the line of progress, in 1818 we find a certain Mr. Thomas Wilson, of Fashine, building the *Vulcan*, which was the first iron vessel—I believe I am right—that was ever constructed. Two years after that we find a vessel of a very remarkable description, called the *Aaron Manby*, and she was the first iron steamer that ever was built. She was built by Mr. Manby and a Captain Napier, whom I well remember at the close of an honourable career in the House of Commons, full of years and honours, and whom I had the honour of being acquainted with as Admiral Sir Charles Napier. That must have been a very curious vessel, because it is reported she was sent in pieces to London, and sent across the Channel under the command of Captain Napier. Well, in alluding to these names, I am trying to prove the position that all classes, from the top to the bottom, have joined in this neighbourhood in the great development of steam navigation, to which I have alluded. Now, I say that you have kept this lead that the people of this neighbourhood of Glasgow took at that early date, for we have seen leaving this great river of Clyde within the last few days a vessel which is to beat the record of all records. Of course, you know I allude to the *City of New York*, and I believe there is also a sister ship pretty nearly ready for launching, which vessels, if they fulfil the expectations regarding them, are to prove extremely formidable rivals to those greyhounds of the Atlantic, the *Arizona*, the *Alaska*, the *Umbria*, and the *Etruria*. I only allude to these things, and have taken, with your permission, this very brief historical survey back, in order to justify me in claiming, as I am about to do, the proud title for Glasgow and the Clyde of being at one and the same time the birthplace, the cradle, the nursery, and the high school of steam navigation.

Now, gentlemen, I do not say that for flattery—I say it because it is the simple truth, and I can say it perhaps with more boldness and confidence coming amongst you as a stranger, as the natural modesty which belongs to the character of all great and eminent men might prevent Clyde men from claiming that proud title. I may make it with entire independence and impartiality, hailing, as I do, from another river on the other side of the island. Of course, I mean the Tyne, which has made no inconsiderable progress of late years in the construction both of cargo vessels, passenger vessels, and ships of the Royal Navy. The great establishments of Elswick and Jarrow have proved to

demonstration their capabilities and their resources in both these respects. I am claiming no more than their due, and I think I may venture to say, without pretending to be a prophet—because there is nothing so dangerous as to prophesy—that Newcastle and the Tyne are yet destined in future years to become a potent—I am quite sure it will always be a friendly—rival even of the Clyde in the construction of the joint fleets of the country. I have alluded to these early patrons of the steam navigation movement for the purpose of proving my position, that Glasgow is entitled to the title which I have ventured to confer upon it; and I would only say, in alluding to them, I do not claim for patronage any more than its due. I think I may say this, that it is perfectly true that merit does not always meet its deserts, and that talent, as of old, is not infrequently hidden under a bushel; and therefore the patronage, the encouragement, and the support of persons of means and position may be, and often is, of immense value to the young struggling student, however gifted by nature, in the early stages of his professional career, when he must, from necessity, climb the hard and often rugged and uneven path of promotion.

Now, there are certain names that I should like to allude to; they shall be very few; and if I name certain persons only, it is not to the exclusion of any others—it is merely to prove my argument regarding the position the Clyde holds. I must, first of all, mention the name of Robert Napier, who, as far back as 1818, applied his great talent and vast energy to the development of steam navigation and the marine engine. We find another interesting epoch, which I am going to allude to. We find that same Robert Napier, in 1840, engining the *Britannia*, and in the two following years three sister ships, wooden vessels, which constitute the foundation of that mighty line, the Cunard Line, which has maintained its high position ever since, the *Etruria* being one of their vessels. There is another name in connection with the establishment of that line which I should not be doing justice to my own feelings and to the feelings of the great majority present, were I not to allude to it—I mean the name of my old and dear friend, Mr. George Burns. I rejoice that he is enjoying a vigorous old age, and that his intellect is as clear as any man's in the room at this moment. We have amongst us a very dear and revered friend of my own, Mr. John Burns, whose kindness and hospitality are only exceeded by his marvellous energy. Another name that I shall mention is that of John Elder, who employed his too short life in the development of the compound engine, with eminent success and skill; and I am happy to think that this week will not close without a demonstration which will be extremely interesting to all of us, and probably painful to some, when the statue erected to him in the park, presented by Mrs. Elder his virtuous and munificent widow, will be unveiled by Lord Lothian, the Secretary of State for Scotland. Mr. Elder joined the firm at Fairfield at the age of twenty-eight, and up till 1869, when Scotland and the nation lost his great services, he was engaged in every description of labour tending to the great development of which I am speaking. I come down now to our own times, and I mention a name which I have the greatest satisfaction in doing, because the gentleman is a very great personal friend of my own, and a member of the Institution—Mr. Alexander Kirk. Mr. Kirk has been long connected with the firm which Robert Napier founded, and has employed his useful life in a further stage of the industry. He has employed himself and his great talents in improving first, and later in developing, the compound engine; and it is greatly, I believe, owing to Mr. Kirk's interesting and patient experiments, on board two well-known vessels, the *Propontis* first, and later on the *Aberdeen*, that the value for sea-going purposes of the triple expansion engine has been proved. It must be a great pride and satisfaction to Mr. Kirk to see that this improvement is almost universally adopted on board Her Majesty's ships, adding greatly to their power, and, I hope, with some economy of fuel. I have endeavoured to show you, by reference to history, the eminent part you have taken in this advance-

ment, but there is one name I should not like to omit mentioning. At present you have the Duke of Argyle as your near neighbour, and there is no man for whose noble character, for whose unrivalled oratorical powers, and for whose eminent literary and scientific attainments I have a greater respect. Although his health is not what it was, he is still taking a deep interest in all that concerns his fellow-men in his immediate neighbourhood. I heard him, only four nights ago, standing up in the House of Lords and fighting a good battle for the purification of Loch Goil, trying to secure for the inhabitants along its banks something like purity of water. I read the Duke's speech with great interest, and wish him every success in that respect. This shows, however, that, even in the case of such eminent men as engineers, it is absolutely necessary now and then to put a bit into their mouths, and to endeavour to curb a little the extraordinary liberties they are sometimes, in pursuit of their great projects, inclined to take, both with "earth" and "water." They require, like other people, to be checked now and then, or, I fear, the earth would become uninhabitable and the waters undrinkable.

Without further trespassing on your time, I shall briefly allude to the papers which are to be read. They appear to me to be as appropriate to the occasion as the invitation and reception the local committee have given us. We are to be treated to a history of the improvement of the navigation of the great Firth of Clyde by a very eminent authority upon engineering. I regret very much to hear that business engagements prevent Mr. Deas from being amongst us; but I have no reason to doubt that gentleman's paper will be most interesting. In connection with ship construction and marine engineering, I think we are sometimes apt to forget what dock and harbour engineers are doing, and have done, for us, because it is perfectly clear that, without their work and skill, it would be absolutely impossible to put our ships into the water at all. We are promised, before the meetings are over, a visit to the Exhibition. I have had something to do with exhibitions on more than one occasion, and, from practical knowledge of the matters connected with them, I am able thoroughly to appreciate the labour and energy necessary for getting them up and conducting them to their termination. I rejoice to hear of the success already attained by the authorities of the Glasgow Exhibition. I look forward—and we all look forward—to visiting the Exhibition; and if proof were wanted of the public spirit for which the banks of the Clyde have almost from time immemorial been illustrious, we should see it in the guarantee fund that was promised at the commencement of that undertaking. It was a remarkably good augury of its success. I am happy to hear that augury has been amply fulfilled, and I trust—because this is always an important matter—that, in addition to being a source of instruction and amusement, it may turn out a financial success. We are also promised an excursion to Inverary; and this, also, I look forward to, knowing something of the beauties of Scotland. I now conclude by remarking that, coming here a comparative stranger, I felt it would only be respectful, at any rate, to address a few observations, and to justify, by clear historical evidence, the statement that the Clyde is entitled to the position I have claimed for it—namely, that of having taken the lead in steam navigation, and kept it up to the present day. (Applause.)

ON THE COMPARATIVE MERITS OF DEEP KEEL AND CENTRE-BOARD YACHTS FOR RACING PURPOSES.

By B. Martell, Esq., Chief Surveyor, Lloyd's Register of Shipping; Vice-President.

[Read at the Thirtieth Session of the Institution of Naval Architects, July 24th, 1888; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The late successes of American yachts fitted with centre-boards when competing with deep keel yachts of the British type have been so striking as to produce an opinion amongst many yachtsmen that yachts of the American design have, in every respect, superior qualities to the deep keel vessels, and that they will ultimately supersede the latter description of yacht for racing purposes. Under these circumstances the subject of the comparative merits of these different types has been thought sufficiently interesting to examine into the qualities alleged to be due to each type of vessel; and the object of this paper is to place before professional and yachting men the results of such investigation with a view to eliciting a discussion amongst those who can claim to speak with authority on this question, more particularly in a locality where so much enterprise and enthusiasm have been displayed in this interesting subject.

I had hoped to have obtained for this purpose drawings of the celebrated yachts *Thistle* and *Volunteer*, in order that an exact comparison might have been made of several of the noteworthy features of these yachts; but in this I have been unsuccessful, and have had to content myself with plans kindly prepared by Mr. Mares in my office from various sources of information, which represent very closely these yachts, and are sufficiently near for instituting the comparisons in question.

The following are the particulars of the two types of yachts :—

	Thistle.	*Volunteer.*
	Feet.	Feet.
Length on water-line	85·6	85·7
Breadth, extreme	20·0	22·2
Depth (moulded)	17·0	13·5
Draught of water (maximum)	13·5	10·0
Displacement in tons	150	130
Freeboard	3·5	3·5

From these particulars it will be seen that the principal difference in the vessels is the relation of depth to breadth.

In our own yachting circles the tendency for some years has been in the direction of decreasing the beam, and to acquire the necessary displacement by increasing the draught. The loss of stability initially, and indeed at all inclinations at which yachts usually sail, resulting from decrease of beam, has been compensated for in practice by carrying large quantities of ballast, amounting in some instances to even more than the weight of the hull, spars, and equipment combined. This diminution of breadth has been carried out of late years to an extent which many experienced yachting men have regarded with disfavour. The tendency no doubt has been fostered by the retention in the minds of many of the erroneous ideas upon the subject of resistance prevalent for many years, and which led to the construction of comparatively narrow and unsafe vessels for general mercantile purposes. Our knowledge of the resistance of ships which we owe to the patient investigation of the late Mr. Froude and his son, scant though it be, is sufficient to show that increase of beam is not necessarily associated with increase of resistance. As soon as that fact in connection with other advantages which breadth gives became sufficiently impressed upon men's minds, a rapid change in the proportions of vessels built for the Mercantile Marine at once took place. The same change, however, has not taken place in the design of British yachts. Perhaps to some extent, in addition to the foregoing considerations, this was owing to the tonnage rule under which yachts, until recently, were sailed. This rule did not take cognisance of depth, and no restriction, therefore, was placed on its increase to any extent which might be considered advantageous.

Our Transatlantic kinsmen, who were not hampered by such tonnage laws, have, on the other hand, placed confidence in breadth of beam and shallow draught, it being apparently their opinion that a vessel of that type would " skim " over the water, instead of having to " plough through it," as in the case of the deeper draught vessel of the narrow type. They long ago, however, discovered that such vessels, without artificial means of preventing leeway, were not superior to, if as good as, those having a greater hold of the water. Hence the introduction of the centre board.

Having thus cursorily traced the growth of the two types of yachts, I propose discussing briefly some of the advantages which they independently possess. Breadth of beam is essential to initial stiffness, if stiffness is to be secured by form alone, or even by form mainly. The narrow, deep yacht has necessarily a low position of the metacentre, and an adequate interval between the metacentre and the centre of gravity can only be secured by artificial means—that is to say, by the use of a large quantity of ballast. The shallow, broad yacht, on the other hand, possesses initial stiffness due to form alone, and although ballast is carried in these vessels also, it is not required to anything like the same extent, and is useful mainly in lengthening out the *range* of

stability. As a matter of fact, therefore, the one yacht is able to stand up under her canvas in a breeze with a small amount of ballast by reason of the stability due to her form, while the other cannot do so without the aid of a large quantity of ballast. As regards this feature of initial stability, which is of the utmost importance in racing yachts, since it practically determines the area of sail to be carried, there is, in my opinion, no doubt that the advantage is on the side of the broad, shallow vessel. Initial stability can be gained more easily and more rapidly by increase of beam than by increase of ballast. The *Thistle* has doubtless considerable initial stability, and carries a comparatively great spread of sail; but she must be regarded as a compromise between the two types, and scarcely representative of either.

The broad yacht can usually carry at the same inclination, in the same breeze, a larger quantity of sail than the narrow, ballasted yacht of the same length and same area of immersed section; or, if both be provided with the same spread of sail, she will stand up better under her canvas, and thus have her sail area more advantageously disposed for receiving the wind's pressure. And this is so at all inclinations at which yachts are usually sailed.

With a view to comparing the *Thistle* and the *Volunteer* in this respect, the stability has been estimated from the drawings referred to, ranging from the upright condition to 90° inclination, when the vessels would be on their beam ends; and the curves marked A and B in Fig. 1 give the results of these calculations for the *Thistle* and *Volunteer* respectively.

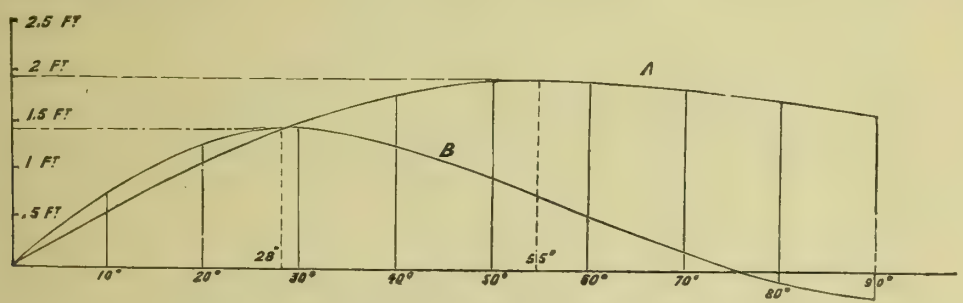


FIG. 1.

In estimating the centre of gravity of the vessels, each is assumed to have masts, rigging, and sails of the total weight of 10 tons. The weight of the hull of the *Volunteer* is taken as 60 tons, and that of the *Thistle* as 70 tons, and ballast has been added to make up the computed displacement, viz.: 60 tons in the *Volunteer*, including centre-board and fittings, and 70 tons in the *Thistle*. The centre of gravity of each of these items is taken, for the purpose of comparison, at a corresponding height in each vessel. The metacentric height in the *Thistle* is thus found to be 3·2 ft., and that of the *Volunteer* 4 ft.

From these curves it will be seen that at all moderate angles of heel, the advantage is considerably on the side of the *Volunteer*. This vessel, however, reaches her angle of maximum stability at about 28°, and beyond this the moment of stability continuously decreases until the angle of about 76° is reached, when the stability vanishes. The *Thistle* on the other hand, although possessed of less stability at small angles of heel, does not reach her maximum stability until about 55° of inclination, and at 90° she has still a large righting moment. Such a vessel is of course uncapsizable, while it is questionable whether the *Volunteer* could be considered safe for an oversea voyage, subject to the sudden gales which might be encountered; or at least, if a race were sailed in the open sea in bad weather, whether it would not be considered prudent or necessary to reduce the sail-spread in weather in which the *Thistle* could carry all her plain sail with perfect safety.

Passing from the consideration of stability or power to stand up under canvas, we come next to the important question of leeway. Running before the wind the British yacht is quite as fast as the American of the same size, if the spread of canvas be as great. The records appear to show that the *Thistle* was even superior to the *Volunteer* in this respect; but, of course, in judging of this, it must be borne in mind that vessels separated by a considerable distance may be subject to great differences in wind pressure, which would possibly account for the *Thistle* gaining slightly on the *Volunteer* on returning in the second race. This point is referred to further on.

If area of middle line longitudinal plane only be considered as a measure of the resistance to leeway, the cause of the superiority of the American vessel will not be evident, as this would appear to be practically the same in the two vessels, viz., 853 sq. ft. in the *Thistle*, and 856 sq. ft. in the *Volunteer*, including the centre-board. As, however, a vessel when making leeway would be under a wind which would cause her to heel, it follows that the vessel which can stand up best will have an advantage over the less stiff one.

The effective lateral resistance is usually estimated from data obtained from the experiments of the late Colonel Beaufoy, on the assumption that the resistance varies as the square of the sine of the angle of inclination of the middle line longitudinal plane to the horizontal.

The late Mr. W. Froude, however, investigated this subject, and stated at the Institution of Civil Engineers in 1871 that this assumption was not correct. At the same time he gave a curve showing for each angle of inclination the value of the resistance per square foot at a given speed. By means of this data the effective lateral resistance of these two yachts has been calculated thus :—

The vessels are supposed to be under the influence of a wind which, with the same spread of sail, heels the *Volunteer* 15°, and the *Thistle* 16½°. The outline of each trans-

verse section is then divided as shown in Fig. 2, into several parts, and the mean angle of inclination of each part to the horizon is measured. The effective resistance of each

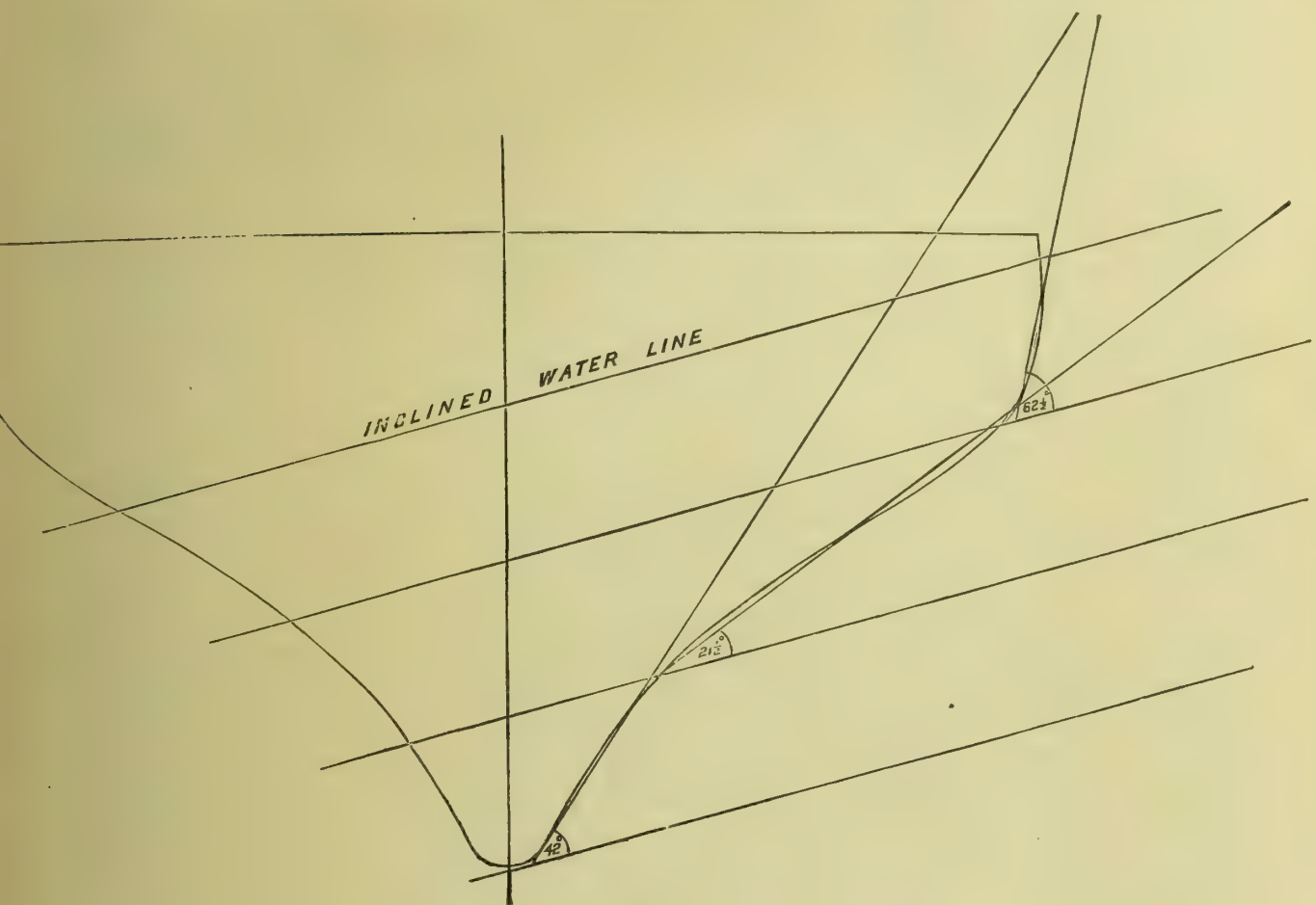


Fig. 2.

of these lengths is then estimated from the data above referred to, and by the usual method these resistances are integrated throughout the length of the vessel. The results obtained by this process are as follow :—

Thistle.—Resistance equal to that due to a plane area of 780 sq. ft. placed at right angles to the line of advance.

Volunteer.—Ditto ditto ditto equal to a similar plane area of 768 sq. ft.

It may be remarked that the results obtained by the process explained would not be quite correct, in that the water set in motion by the upper part of the vessel, inclined at one angle to the horizon, would undoubtedly affect the resistance of the lower part of

the vessel inclined at a different angle, but it is considered that a very fair comparison may by this means be made of the relative resistance of two vessels of the same type.

The relative resistance to leeway thus calculated is slightly in favour of the *Thistle;* while, if the areas of the middle line planes are compared, the vessels are seen to be practically the same. The cause of this slight falling off in the *Volunteer* is plain when the breadth and draught of the two vessels are considered; thus in the *Volunteer* $\frac{\text{breadth}}{\text{draught}} = \frac{22{\cdot}2}{10} = 2{\cdot}22$, and in the *Thistle* it is $\frac{20}{13{\cdot}5} = 1{\cdot}5$ nearly. The *Thistle* thus presents her side far more square to the direction the vessel is being driven, and were it not for the centre-board of the *Volunteer* she would undoubtedly drift to leeward much more quickly than the *Thistle*, as may be seen from a comparison of the figures calculated as above, with and without the centre-board, viz., the area of the middle line plane without the centre-board is 732 sq. ft., and of the centre-board 124 sq. ft., or a little over 16 per cent. of the whole, while the effective area for resistance to leeway, calculated as before explained, of this vessel without centre-board is only 634 sq. ft., and of the centre-board 134 sq. ft., or 21 per cent. of the whole, showing clearly the effectiveness of the centre-board.

The cause of the greater resistance to leeway undoubtedly possessed by the *Volunteer* must, however, be accounted for by the fact referred to by Mr. Froude in the discussion on the paper alluded to, that the *leading part* of a plane moved obliquely through a fluid has a much greater resistance per square foot than the remainder of the plane. This greater resistance is also referred to by Mr. Dixon Kemp, in his valuable treatise on "Yacht Architecture," and would appear to be owing to the leading part of the plane being continually brought into contact with fluid at rest, while the remainder of the plane acts on fluid already in motion. It will readily be seen that the triangular centre-board of the American yachts, having a long leading edge, is most advantageously placed in this respect, and its resistance per square foot at a given speed is much greater than that of the ship proper.

Turning now to a consideration of the means of propulsion of yachts, it appears to be a well-established fact that American sailmakers have for a long time made their sails much flatter than is the practice in this country, and, further, that the advantage of doing so is so far recognised in this country that suits of sails are now frequently ordered in America for British yachts.

In the diagram, Fig. 3, suppose A B to be the horizontal section of a jib, P the direction of the wind relative to the vessel, and suppose the sail under the influence of this wind to assume the shape indicated by the dotted line A C B, this wind pressure produces a tension on the material of the sail which acts on both the stay at the fore edge and the bolt-rope at the after edge. The tension on the after edge is a propulsive

force, while that on the forward edge is a retarding force, and the excess of the resolved part of the latter above the resolved part of the former, in a fore and aft line, is the net effective force of the sail. Now, it appears from observation that the ballooning is found nearer the forward than the after edge, and consequently, when the vessel is sailing with the wind not greatly before the beam, the retarding force R_2 acts at a greater angle to the fore and aft line in a balloon sail than in a flat sail, and the effective force of the wind on the sail is thereby increased.

The late Mr. Froude, at the Institution of Civil Engineers, in the discussion previously referred to, mentioned cases where the rounded cut of the luff of a jib produced a bagginess just abaft the stay, which swelled out under the influence of the wind so much that the "bag" could be seen on the fore side of the stay by an onlooker standing square to the vessel's course.

In such a case the sail's action on both stay and bolt-rope is propulsive; but it is evident such a sail would soon "lift" if the vessel were forced close to the wind, owing to the wind pressure on the back of the fore part of the sail being at least equal to that on the fore side. Indeed, it is evident from a consideration of the diagram that when the vessel is sailing close to the wind any considerable amount of ballooning of the sail will cause the fore part to be parallel, or nearly so, to the direction of the wind, when its propulsive effect would be lost, while the after part of the sail standing across the wind will tend to form a back sail.

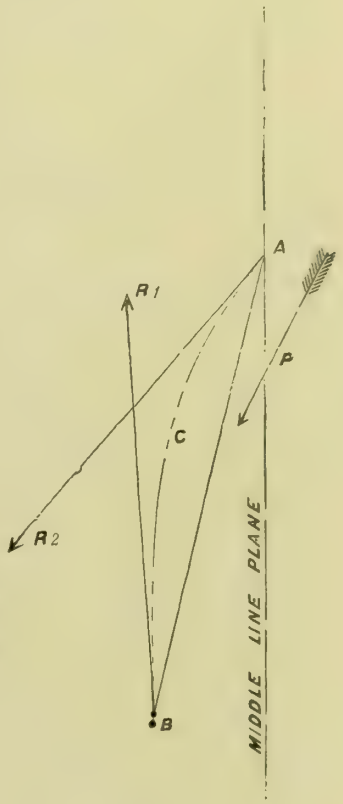


Fig. 3.

The conclusion appears to be that if the vessel is not sailing very close to the wind the advantage lies with the balloon sail; but if it is necessary to press the vessel close to the wind, a very distinct advantage is gained by having flat sails, which, by avoiding any back pressure, get the utmost effect out of the wind.

As regards the resistance to propulsion of the two vessels, the wetted surface of the *Thistle*, calculated from the plans alluded to, appears to have been about 2,160 sq. ft.; and of the *Volunteer* 1,980 sq. ft., not including the centre-board, and 2,230 sq. ft. with the centre-board. If anything, the frictional resistance per square foot of surface would, from the result of Mr. Froude's experiments, be somewhat less in the *Thistle* than in the *Volunteer;* further, at low speeds the wave-making resistance would be in favour of the *Thistle*, and not until very great speeds were

reached, at which the formation of transverse waves begins, would the *Volunteer* reap any advantage over her narrower rival.

In the second race between the *Volunteer* and *Thistle* they had to beat out 20 miles in the teeth of the wind, and, apart from the possibility of the wind blowing with different force on vessels separated by a considerable distance, the results of this race present on analysis some interesting features. It is estimated that in the run out the *Volunteer* covered a distance of 27 miles in 3h. 45m. 50sec., while the *Thistle*, owing to the greater leeway made, sailed about 29 miles in 4h. 0m. 39sec. The mean speed of the *Thistle*, from these figures, was 0·8 per cent. greater than that of the *Volunteer*.

In returning the yachts sailed each 20 miles, the *Volunteer* in 1h. 57m. 7sec., and the *Thistle* in 1h. 54m. 12sec., giving the advantage of 2·5 per cent. in speed in favour of the *Thistle*. Now, in the run out the *Volunteer's* centre-board would be lowered, thereby increasing the surface friction, and in the return this cause of resistance would not occur; and yet in spite of this the *Thistle* increases her advantage by about 1·7 per cent. of the speed. Further, the wave-making resistance at the high speed of the return journey could not, as previously explained, help the *Thistle* as compared with the *Volunteer*, and consequently a very considerable portion of this difference must be accredited to the flatness of the *Volunteer's* sails in beating out against the wind. Of course, on the results of one race it is impossible to form a decided judgment, but the evidence in this case forcibly points to this conclusion.

And here it may be remarked the great advantage which has been derived by the naval architectural profession from the experiments made by the late Mr. W. Froude, and continued by his son, and seeing that Professor Jenkins assisted in conducting many of these experiments, I feel sure that I am only expressing the wishes of all here present when I venture to hope that the time is not far distant when Glasgow University will possess an experimental tank, where the students may conduct similar experiments, guided by the sound judgment of the Professor of Naval Architecture at the University, when many of the doubts which now exist in dealing with such subjects as this will be solved, and surer advances in the profession be attainable.

I feel at the same time much pleasure in acknowledging the assistance I have derived from my friends Professor Jenkins and Mr. T. C. Read, of Lloyd's Register, in preparing this slight review of an interesting subject.

In conclusion, I have only to add that in summing up the results of this brief investigation, it would appear that the American type of yacht possesses greater stiffness, and therefore greater sail-carrying power; it has, by reason of the centre-board, greater resistance to leeway, is fitted with better sails for close-hauled sailing, and has practically no more skin friction and wave-making resistance at all ordinary speeds; while the only point on which the British type has the advantage is, that it is safer

in bad weather in the open sea with a large spread of canvas. It is not surprising that under these circumstances all the recent trials of speed between the British and American types should have resulted in the triumph of the latter. It now behoves British yachtsmen to consider whether it is expedient for them to make sea-going qualities a *sine quâ non* in a racing machine, or to sacrifice high speed in bad weather at sea in order to obtain greater speed in the usual conditions under which these vessels will be raced, which is, after all, the principal reason of their existence.

DISCUSSION.

Mr. G. L. Watson (Member): My Lord and gentlemen, we are all, I feel sure, very much indebted to Mr. Martell for the most interesting paper he has given us, and for the great trouble and ingenuity he has shown, not only in deducing conclusions from the data before him, but in the preparation of the data from which he has drawn his conclusions. I think, however, there are one or two points where *his* facts do not agree with the actual facts as observed. I would refer in particular to the relative stability of the two vessels. Mr. Martell assumed the *Volunteer* to take a heel of 15, and the *Thistle* a heel of 16½, under the same wind pressure, and upon that basis a good many of his assumptions were made. The fact is, that in sailing the second race, where both vessels were at a considerable angle of heel, I carefully observed this, and although it is difficult to judge the heel on board, I verified my observations by those of several gentlemen who watched the race and got the boats on end. These three gentlemen—good yachtsmen, and well competent to judge on questions of this sort—were of opinion that there was a difference of something like three degrees (more, certainly, than *I* thought) in favour of the *Thistle*. She was to that extent the stiffer. I think it is unfortunate that so much attention has been paid to these cup races. They have come very prominently before the public, and the public judged from them the relative merits of the centre-board and the keel boat. There have been very many other races between the two kinds tried over the whole season with great variety of weather, and the result has been different. The *Clara*, one of Mr. Fyfe's boats, had won almost every race she has sailed against the centre-board. The *Bedouin*, which is quite an old boat, is still acknowledged to be about the fastest of her class, and her record is favourable when compared with the centre-board boats of the same length. The *Madge*, then only a second-rate ten-tonner in this country, won seven races out of eight against centre-boards of the same length; and the *Shona* did the same thing a year ago. One of Mr. Burgess's boats, the *Papoose*, has not only beaten boats of her own length, but new boats of 4 ft. greater length. Coming again to our own country, on the Thames there is a new class, in which there is no restriction as to the keel or centre-board. A man may build just what he thinks is likely to be the fastest. The result of these races I have just got this morning. In the 21 ft. class we have five boats built; two have fallen out of the racing early in the season. The keel boat had nine starts, six first and three second prizes. The best of the centre-boards had seven starts, one first and five seconds; and the other, six starts, with two first and one second. I give results in tabulated form. My own opinion with regard to the centre-board and the keel is that the keel boat, if properly designed, and unfettered as to dimensions, can always be made to beat the centre-board. That implies that the *Thistle* was not properly designed, and I daresay that may be about the right of it. Mr. Martell referred to the sails, and tried to let us down easy at the expense of the sailmakers. That I don't think is fair. With regard to the sails on the *Thistle*, these, along with the sails on nearly all racing boats, within

the last seven or eight years at least, were absolutely perfect. I do not see that they could be improved. It may seem strange to say, but I am not sure but that on the first day's racing the sails were actually too flat. The fact is, that an absolutely flat sail—I do not know how to account for it, and I cannot tell how it is—will not drive a boat as well as a slightly slack sail, in light winds, and I think on the first day the *Volunteer* had slightly the advantage in that respect, as her sails were not so flat as ours. As for the ability of our sail-makers to cut flat sails, they are, in my opinion, superior to the Americans. Mr. Martell spoke of some British vessels ordering American sails, but I know of no racing boat here with American sails. I think, my Lord, that these are all the remarks I have to make in connection with this paper.

Professor P. Jenkins (Member) : My Lord, Mr. Martell has very properly observed that when a vessel is sailing over an all-round course, so many elements affecting her efficiency as a racer intervene, that it is extremely difficult to assign to any one element its proper relative position—that it is extremely difficult, for instance, from the results of a race on an all-round course, to infer that one vessel has a smaller direct resistance than another; and similarly in respect of the efficiency of the sails. The question of the direct resistance is one of the most important in the design of a yacht, but as the proportions of yachts of the American type differ so greatly from those of yachts of the British type, it would be difficult, from the results of experiments upon either ships or models hitherto made public, to conclude with any certainty as to which of two vessels of the different types, having the same tonnage, has the smaller direct resistance. The surface friction resistance, which is the main source of resistance at low speeds, is, of course, calculable, and, so far as I have been able to judge, this element was pretty much the same for the *Volunteer* as for the *Thistle*. As the members are aware, the other chief source of resistance, viz., wave-making, is deducible only by experiment. Some years ago I had the pleasure of assisting the late Mr. Froude in the conduct of his experiments upon the models of vessels at the Admiralty tank, Torquay, and during that time some experiments were undertaken which were very instructive, and threw a great deal of light upon this particular branch of the general problem. The experiments were made on a series of models of common length and displacement, but widely differing proportions of beam to draught, each of the models, moreover, being passed through a corresponding series of gradations of fineness. My recollection is that in all cases the wave-making resistances of the broader and shallower forms were the greatest up to the highest speeds included in the experiments which would be equivalent to about 11 knots for an 85 ft. vessel.* So far as those experiments went, the narrow deep vessel was shown to be superior to the broad shallow one as regards total direct resistance, and would undoubtedly prove the faster boat were it not for the fact that the latter when fitted with the centre-broad acquires an advantage on an all-round course in respect of leeway which more than counterbalances the loss of speed due to the greater resistance. The experiments appear to have been in a measure confirmed in the race between the *Thistle* and *Volunteer*, as the former yacht was reported to have invariably gained on the latter when running before the wind. As regards the stability of the two types of yacht, it has always appeared to me that the broad yacht has a very great advantage in this respect over the narrow one. The broad yacht has initial stability of form which enables her to stand up well under her canvas, and to carry a greater spread at a given angle of heel than the narrow yacht. It is true that she is comparatively deficient in range; but yachts of any size, such as the *Volunteer*, have certainly range enough to make them safe against capsizing with moderately careful handling. The narrow yacht, even with the heavy ballasting now common, is more tender at

* Diagrams were exhibited at the meeting illustrating the relative resistances of the various forms.

moderate inclinations than the broad yacht, and although she has great stability at large inclinations, it is so situated as to be quite valueless for racing purposes.

Captain C. Penrose FitzGerald (Associate): My Lord, in looking at the diagrams before us, I think it is almost plain that the *Volunteer* ought to beat the *Thistle*. She has greater initial stability. The *Volunteer*, evidently, has several degrees' difference in angle to the *Thistle*; at all ordinary heels her stability is greater, and other things being equal she ought to beat her. I am sure, however, everyone will admire the pluck of Glasgow and the West of Scotland in wishing to bring back the cup, and I hope they will yet be successful.

Mr. H. H. West (Member of Council): My Lord, I do not intend to approach this subject from the point of view of a racing yachtsman. That, for more reasons than one, is not my strong point. But I remember that several years ago (November, 1869) a paper was read by Mr. Montgomerie Neilson before the Institution which is our host to-day, on a Proposed Channel Ferry Steamer. The characteristic feature of this design was a very light draught with a very deep movable centre-board keel which could be lowered in deep water to give this broad, shallow vessel greater steadiness at sea. I should like to have the opinion of such an authority as Mr. Martell on what would be the probable behaviour of such a ship at sea. Of course the centre-board would have little or no practical influence on her statical stability, but we know that outside bilge keels have a very palpable influence in steadying and reducing the rolling motion of a vessel, and, *a priori*, one would expect a deep centre-board to have at least as great an influence. The matter came before me recently in a proposal to build a steamer with a movable centre-board keel, for a trade involving a long deep sea voyage combined with having to pass over a bar into a comparatively shallow river. I gave some consideration to the structural details which such a scheme would require, but as it did not promise commercial success it was abandoned. One of my difficulties, however, lay in the consideration that, inasmuch as the vessel would always have a heavy surf to encounter on the river bar, probably as severe as any sea ordinarily met with on her voyage, and must necessarily then draw in the centre-board on account of its excessive draught, any advantage from its use would have to be given up just at the time when it would be of most service. I nevertheless think that there might be circumstances in which a movable centre-board keel would prove a useful adjunct to some special types of cargo steamers. If Mr. Martell would favour us with his opinion on this point, I, for one, should be much obliged to him.

Mr. W. H. White, F.R.S. (Vice-President): My Lord and gentlemen, in the matter of yacht tonnage and racing I am a complete outsider, but an outsider who for the last twenty years has taken great interest in watching what has been done; and I do not think sufficient weight has been given in this paper or discussion to the effects of yacht-designing, or the rule of tonnage which prevails at any given time. Gentlemen like Mr. Watson are naturally not averse to changes in the rules of tonnage. Although a change gives them a difficult problem to deal with, it also affords great opportunities of distinction. In the particulars put before us to-day, as to the boats which have been lately racing on the Thames, in whose design there has been considerable freedom of choice on the part of the designer, under fixed conditions of length, we have an example of what, I think, has been constantly occurring during the last few years—namely, that the rule of tonnage, instead of being fixed or hard and fast, has been changed from time to time, and these changes have produced considerable alterations in the types and proportions of racing yachts. The old Thames rule of tonnage, which has been alluded to by one of the speakers, has been long ago departed from under the Yacht Racing Association Regulations, and we do not any longer see those extraordinary examples of extreme narrowness

and very heavy ballast which were formerly in vogue. When people build yachts for racing, the existing rule of tonnage must very greatly influence the designer. He aims at winning prizes. The rules of tonnage which have been in force here, whatever their faults may have been, undoubtedly produced vessels that were thoroughly seaworthy in the worst weather. It has been alleged that the American style of yacht, with its considerable beam and shallowness, is not seaworthy under many circumstances when the English yacht could live. So far as my own knowledge of the subject goes, all the cases in which American yachts have capsized have been associated with some condition of unpreparedness—either the hatches have been open, or the weights have been unsecured, and have shifted. In all these cases the conditions have not been those which should prevail when vessels are in racing trim in rough weather. No doubt American yachts require skilled and careful management; but that seems to me only a reasonable requirement. I agree with Professor Jenkins as to the advantage which should accrue from having greater beam in racing yachts, provided always that the rule of tonnage gives that increase a fair chance for racing in the time allowances. There is only one other point I would like to mention. If I remember rightly, the *Volunteer* had a larger proportionate spread of sail than the *Thistle*, and if so, that must have had very much to do with her superior performance as compared with the *Thistle*, because the driving power of the former would have been much larger than that of the latter vessel.

Mr. Henry Lamont (Associate): My Lord, with your permission I should like to ask whether in America the *Thistle* sailed with the same mainsail as that which she used on the Clyde. It was a matter of remark amongst yachting men on the Clyde that the mainsail was very much drawn out on the boom, and it was felt that if it was sailed in that condition in America, it could not possibly have had the same amount of propelling power as if the sail had been properly set. I have been told that the Americans are adepts in the making of laced sails, and that the *Volunteer* within a few days of the race had a brand-new mainsail properly set, according to American idea. Perhaps Mr. Watson will be good enough to afford us some information on this point.

Mr. G. L. Watson: The same sail was used in America as was used on the Clyde, but I do not think any fault could be found with the sails as they were set in America. I never saw a more beautifully set sail than the one we had set on the first day. The second day it was pouring rain—everything was drenched, and the sail certainly dragged itself out of shape, while with the baggier sail of the *Volunteer*, the rain rather flattened it than otherwise.

General R. R. Mainwaring (Associate): The question of the centre-board, deep keel, and hull of a vessel should, I fancy, be calculated by the specific gravity or weight of the body of water. Now it is a well-known axiom that the deeper a sounding lead is sunk the greater the difficulty of recovering it will be. This is caused by the weight or pressure of the water above the lead. We will call this the power of resistance, which is equally powerful horizontally as vertically. So the greater the depth a keel or centre-board is sunk, the greater will be the resistance. But in a vessel we have to consider not only the forward motion, but also the lateral—the first to be promoted, and the other prevented, as much as possible. The centre-board and the deep keel act both in this way, keeping the the vessel up to wind, by counteracting the effect of the wind, and enabling the vessel to maintain a perpendicular position, or nearly so, and thereby showing a less front or body for resistance to the water, the space or body of resistance then saved being greater than that of the centre-board or keel, and their weight acting as a counterpoise to that of the wind on the sails. Now as to the hull, the broad beam having greater support than the narrow tends to keep the vessel more on an even keel, and I advocate that the beam should be not more than one-third of length from stem, for this

reason—that it being so placed shows a less length to the power of resistance. Then, again, the horizontal bow (as I call it for want of a better) gives less resistance than the vertical, and also gives the vessel—the beam being placed, as I said, one-third from stem—more floating power. When depressed by wind or wave, with a clear run aft, the wave runs off without any hindrance. I agree with the Chief Surveyor, Lloyd's Register of Shipping, as to the American sails. Now, as to centre-boards, they were prohibited by Englishmen about the same time as the shifting of ballast.

Mr. H. H. Laird (Member of Council): My Lord, in speaking of the use of centre-boards in vessels of light draught, I may perhaps be allowed to mention that the paddle-wheel sloop of war *Nemesis*, which was built in 1839 by my father for the Honourable East India Company—a vessel with 7 ft. draught, which went round the Cape in 1840—was fitted with two drop keels, working in trunks, the object being to give her steadiness, and make her more weatherly when under canvas with floats removed, as was the case during the greater part of the voyage. I believe the same thing has not been continued, as light draught steam vessels do not now depend on sailing power.

Mr. G. L. Watson: It is very difficult to obtain accurate information as to the sail area of the *Volunteer*, but so far as I can learn or judge, I think it is about 8 per cent. more than that of the *Thistle*.

Major Barrington Baker (Associate): My Lord and gentlemen, I may perhaps be permitted to say that I have raced in both deep-keel and centreboard boats, and my experience is that extreme beam entails greater resistance than great depth. I have had lately some most interesting discussions on this point with Mr. Froude at the Tank at Haslar, and have come to the conclusion that under the present rules a boat should not have extreme beams, but more than at present would be an advantage. In regard to the safety of centre-boards, there is no reason why they should not be as safe as others; but I hope that we shall not for some time yet see in our newspapers a paragraph headed, "Capsizes of the Week." This is a very common one in the American newspapers, and there are, indeed, every week instances of boats capsizing over there, generally with loss of life.

Mr. B. Martell (Vice-President): My Lord, my paper was intended simply for the purpose of raising a discussion, and if it has not done more I am delighted to know that it has done one thing, namely, that it has brought from Mr. Watson information which could not otherwise be obtained, and which he must have found like drawing an eye-tooth. As to the comparison between the *Volunteer* and the *Thistle*, it does not purport to be strictly accurate. It was a comparison intended only to show that vessels of the respective types using the same sail area would incline to the conditions I have stated. But there is one thing should be borne in mind: Mr. Watson, with his usual modesty, has stated, in his desire to uphold the British form of yacht, that his yacht was not well designed, and that if she had been a proper yacht she would have beaten the *Volunteer*. Now I do not think that very fair, because up to the time the *Thistle* went to America she had beaten every yacht with which she came into competition. Why or how she was beaten by the *Volunteer* I can only suggest as embodied in the paper.

THE RIVER CLYDE.

By James Deas, Esq., M.I.M.E., F.R.S.S.A., Engineer Clyde Navigation.

[Read at the Thirtieth Session of the Institution of Naval Architects, July 24th, 1888; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

Introduction.

The Author has much pleasure in complying with the request of your noble Chairman, conveyed to him by his friend Mr. John Inglis, and your Secretary, to furnish a short paper on the Clyde, although to him it is now "an oft told tale."

It is but natural that your Institution should desire, especially on their visit to Glasgow, to have some information regarding those improvements of the Clyde, which, though not the birthplace of steam propulsion in Europe—Dalswinton Loch, Dumfriesshire, having that never-to-be-forgotten honour, exactly 100 years ago—received into its waters at Port Glasgow, in June, 1812, the precursor of that mighty fleet, the steamships of the present day—the *Comet*, 42 ft. long by 11½ ft. beam, 4 ft. draught, and 3-horse power, which have enabled it to play so important a part in the development of the Mercantile and Defensive Steam Navies of the world, culminating for the present in the launch, on 16th March last, from Messrs. J. and G. Thomson's yard at Clydebank, about 6½ miles below the Harbour of Glasgow, of the Inman and International twin screw liner *City of New York*, 580 ft. long by 63¼ ft. beam, 30 ft. draught, 10,500 gross tonnage, and 20,000 horse-power.

These improvements have raised Glasgow within the short period of 88 years from a second-rate inland provincial town, with a population of 77,000, to be the second city of the Empire, with a population (including its suburbs) of 770,000; the chief seaport of the West of Scotland; increased the value of the lands on the river's-sides, from Glasgow seaward, a hundredfold; created the burghs of Govan, Partick, and the numerous other burghs which environ Glasgow; given wealth to thousands, and the means of life to hundreds of thousands of the inhabitants of the northern portion of the Kingdom; and emphasised in a marked degree the local epigram, "Glasgow made the Clyde, and the Clyde has made Glasgow."

"The Tweed, the Annan, and the Clyde
All rise from one hillside." *

But how different their careers and destinies! The Tweed, immortalised by Sir Walter Scott, after a course of some 100 miles, falling into the North Sea at Berwick, and famous chiefly for its king of fish, the salmon; the Annan, after a quiet and pastoral course of only 35 miles, reaching its bourne in the Solway Firth at Annan; while the Clyde, after a course of 98 miles, and draining an area of 945 square miles, reaches deep water at Greenock, and thence to the Atlantic Ocean, passing over in its course its famed falls near Lanark, through the celebrated orchards of Clydesdale between Lanark and Hamilton, and thence to Glasgow through the wealthy mineral district which it drains, and is famed the wide world over, as the creator, by its improvement, of the great city in which you are now assembled, the home of almost every industry under the sun, and the greatest shipbuilding river in the universe, furnishing to all nations the means of communication with each other by vessels built on its banks.

Numerous waters, rivulets, burns, and rills join in the formation of the Upper Clyde; the highest of these, which take their rise in the mountain ranges on the confines of Lanarkshire and Dumfriesshire, being the Daer Water (from which the Earl of Selkirk's eldest son takes his courtesy title of Lord Daer), the Powtrail Water, and the Clyde Burn: the last 1,028 ft. above Ordnance Datum, where it crosses under the Caledonian Railway, at the Summit Station, in a conduit 12 ft. 6 in. wide by 2 ft. 3 in. high.

The Daer and the Powtrail meet together before their confluence with Clyde Burn, about two miles below Summit Station; and although Clyde Burn is considerably smaller than either of the other two, the stream from this point takes the name of the River Clyde.

The chief tributaries of the lower Clyde are only three in number:—

First.—The Kelvin, noted in song, which rises in the Campsie hills due north of Glasgow, forms in its lower reaches the present western boundary of the city of Glasgow, and, after a course of only twenty-one miles, discharges into the Clyde at Govan Ferry, the western limit of the harbour.

Second.—The Cart, which joins the Clyde about half a mile below Renfrew, and is formed by the junction, about three-quarters of a mile from the Clyde, of the White Cart and the Black Cart, the former about nineteen miles in length, rising in the Eaglesham district of Renfrewshire, about ten miles due south of Glasgow, and on which the prosperous town of Paisley is built; and the latter about nine miles in length, rising in the neighbourhood of the town of Lochwinnoch.

* This is a poetic licence. They rise, however, within four or five miles of each other.

Third.—The Leven, well known in cotton manufacturing circles for its Turkey-red dye works, which discharges the surplus waters of Loch Lomond—the queen of Scottish lakes—ruddy coloured, into the river, immediately west of Dumbarton Rock, after a course of seven and a half miles, and on which the town of Dumbarton stands, erstwhile famed for its glass-works, but in the present day better and more widely known for the extensive shipbuilding yards and marine engineering works of Messrs. William Denny & Brothers, and Messrs. A. McMillan & Sons.

The Clyde in its course to the sea, unfortunately for its character of salubrity, receives both the domestic and manufacturing sewage of upwards of 1,000,000 inhabitants, and the 39,574,000 gallons of water which Glasgow daily receives, 35,000,000 gallons of which are from Loch Katrine, add considerably to its volume.

The Forth and Clyde Canal, thirty-five miles long, opened in 1790, and whose locks admit of the passage of vessels of 68 ft. keel, 19 ft. beam, and 8½ ft. draught of water, joins the Clyde at Bowling, and a branch from the Canal to the Clyde, opposite the mouth of the Cart, gives direct communication between the Canal and Paisley.

The Caledonian Railway follows very closely the course of the Clyde, crossing and recrossing it many times, its last crossing being immediately below Glasgow Bridge, where the width of the river is 420 ft., and they do not part company with each other until they both terminate in the Clyde estuary below Greenock.

The Author will, in dealing further with the subject, put his remarks under the following heads :—

1. History of the Improvement of the River.
2. Progress of the Harbour and Commerce of Glasgow.
3. Rise and Progress of Shipbuilding on the River and its Tributaries ; and
4. Short description of other Harbours on the River.

I.—History of the Improvement of the River.

In pre-historic times Ancient Britons must have paddled their own canoes in its shallow stream, as dug-outs have been unearthed not only on the banks of the river at Glasgow and Bowling, but even at the Cross of Glasgow, fully 500 yards from the present margin of the river : and Roman legions must have camped on its banks while they were engaged in constructing, under Agricola, 80—81 A.D., a chain of forts between the Clyde, near Bowling, and the Forth, near Bo'ness ; and under Antoninus Pius in 140 A.D., in connecting these forts by ramparts of earth and stones, with a deep and wide ditch outside, and a paved military road along the inner or south side, to check the inroads of the Caledonian barbarians.

Upwards of 300 years ago—in the summer of 1566—the Magistrates and Town Council of Glasgow made the first attempt on record to improve the river by detachments of the inhabitants of the City of Glasgow, joined by contingents from Renfrew and Dumbarton, endeavouring to open up what the chronicler of that day called "a formidable sandbank" at Dumbuck, about two miles above Dumbarton and about ten miles below Glasgow Harbour, at which they laboured for several weeks, residing during the time in timber huts built on the river banks near the scene of their operations.

This attempt must have proved of little value, as Thomas Tucker, one of Cromwell's Commissioners, in describing Glasgow and the river in a report dated November 20, 1656, ninety years thereafter, says :—

"The situation of this towne in a plentiful land, and the mercantile genius of the people are strong signs of her increase and growth were she not chequed and kept under by the shallowness of her river, every day increasing and filling up soe that noe vessels of any burden can come nearer up than within fourteene miles, where they must unlade and send up theyr timber and Norway Trade in rafts or floates, and all other commodityes by three or foure tonnes of goods at a time in small cobbles, or boates, in three, four, five, and none above six tonnes a boat."

Nor can much benefit have resulted from the carrying out of the following Minute of Council, dated May 8, 1740 :—

"The Councill agree that a tryall be made this season of deepening the river below the Broomielaw, and remit to the magistrates to cause do the same, and go to the length of £100 sterling of charges thereupon, and to cause build a flatt-bottomed boat to carry off the sand and chingle from the banks."

Up till 1768 the river between Glasgow and the sea remained practically in a state of nature, choked up with sandbanks, impeded by numerous fords, and only suitable for herring boats and such like craft.

Thus the river remained, expanding in useless width as it decreased in depth, until in that year, John Golborne, civil engineer of Chester, appeared on the scene, and it was to him that Glasgow is indebted for the first really successful step in the improvement of its navigation, and by his system of contracting the river by the construction of rubble jetties, and the removal of sand and gravel shoals by ploughing, harrowing, and dredging, the first marked improvement of the navigation was effected.

In 1773 he took a contract to make Dumbuck Ford 6 feet deep and 300 feet wide at low water for £2,300; and in September, 1775, the Town Council, on the recommendation of the merchants, gave him £1,500 for deepening the river 10 inches more than he was bound to do by his contract, presented him with a silver cup, and gave his son £100. Generous Town Council! happy engineer!

From 1781 on till 1836, the works carried on for the further improvement of the river under the direction consecutively of Golborne, Rennie, and Telford, consisted chiefly in the shortening of some, and the lengthening of other of Golborne's jetties, the construction of additional jetties, the connecting of the outer ends of these jetties by half-tide training walls on both sides of the river, so as to confine the water and increase the ebb scour, and the removal of hard shoals by dredging.

It was not till 1836 that the river from Glasgow to Port Glasgow was treated as a whole, and a true appreciation shown of its future by the Clyde Trustees' then Engineer Logan, in the laying down of river lines, which, with some slight modifications and expansions, have up till now formed the limits of the river's improvements.

Parliamentary plans on these lines approved of by James Walker, Consulting Engineer to the Trustees, were submitted to and sanctioned by Parliament in 1840; but so inadequate was the appreciation of the depth required, that 20 ft. at high water neap tides was recommended by Logan as the extreme depth of the river and harbour, and a clause in the Act empowered the deepening to proceed until every part thereof shall have attained at least a depth of 17 ft. at high water neap tides.

The depth in the Harbour of Glasgow at the present time is from 25 ft. to 29 ft., and in the river from 27 ft. to 29 ft. at high water neaps, high water springs being about 2 ft. higher. The average tidal range of spring tides at Glasgow is 11 ft. 2 in., and at Port Glasgow 10 ft.; and of neaps at Glasgow 9 ft. 2 in., and at Port Glasgow 8 ft. 3 in.

While jetties and training walls or parallel dykes performed a useful part in the early improvement of the river, it is to persistent dredging that the enormous increase in the magnitude of the river since 1840 is due.

The early dredging was performed by large rakes, or porcupine ploughs, as they were called, because they were provided with strong iron teeth, wrought by hand capstans, which drew the material from the bed of the river on to the banks.

Hand-wrought, and subsequently horse-wrought, dredgers with small buckets on a ladder succeeded the plough, and in 1824 the first steam dredger was started on the river. It dredged only to 10 ft. 6 in. Now several of the dredgers employed can work in 35 ft. depth of water.

It is undoubtedly to the application of steam power to dredgers, and the subsequent adoption of steam hopper barges—a French invention—for carrying the dredged material to the sea, that the rapid enlargement not only of the Clyde and the Harbour of Glasgow, but of the Tyne, the Tees, and several other similar rivers in recent years are due. But for the introduction of the latter, it would have been physically, finan-

cially, and otherwise impossible to have disposed, within so limited a time, of the enormous quantities of material which have been dredged from these various rivers and harbours.

Up till 1862, all the material dredged from the River Clyde and Harbour of Glasgow was loaded on punts holding eight cubic yards, and deposited on the alveus or foreshores, or the low-lying land adjoining the river.

Many acres were thus reclaimed, to the aggrandisement of the riparian proprietors, to whom the Trustees required to hand over the ground free of cost.

The adoption and speedy acquisition by the Trustees of steam hopper barges, holding from 240 to 320 cub. yds. each, removed all these obstacles, and enabled the deepening, widening, and straightening of the river and harbour to be proceeded with more rapidly, without hampering the Trust's finances, or seriously obstructing the navigation with steam tugs and trains of punts. The result has been that while in 1861 the total quantity dredged and deposited on land was 593,176 cub. yds., the total quantity dredged in 1887 was 1,319,344 cub. yds., only 64,000 cub. yds. of which was deposited on land. The total quantity dredged during the last forty-two years amounts to 32,027,834 cub. yds., the quantity in the first twenty-one years being 9,091,544 cub. yds., and in the last twenty-one years, 22,936,290 cub. yds.

The best thanks of river and harbour authorities, such as the Clyde Trust, of River and Harbour Engineers, and of the community at large, are justly due to those marine engineers and shipbuilders who have made dredging plant a specialty, among whom the firms of Messrs. William Simons & Co., and Lobnitz & Co., Renfrew, and Fleming & Ferguson, Paisley, occupy deservedly prominent positions.

In 1755, the Clyde at Glasgow was only 15 in. deep at low water, and 3 ft. 8 in. at high water, while the depth at Marlinford, three miles below the harbour, was 18 in., and at Erskine, or Kilpatrick Sands, about eight miles below, and at Dumbuck Ford, ten miles below, only 2 ft. at low water.

In 1781, the depth at Dumbuck Ford was 14 ft. at low water; it is now 20 ft.

In 1806, Telford reports that on February 14 of that year the *Harmony*, of Liverpool, came up with ordinary spring tide, drawing 8 ft. 6 in. of water; but up till 1812, the river from the harbour downwards to Bowling was so shallow, that the *Comet* required to leave Glasgow and Greenock, respectively, at or near high water to prevent it grounding in the river. An old gentleman who had been connected with the Clyde for upwards of fifty years, informed the author a few years ago that he made a voyage in the *Comet* in 1812, leaving Greenock at 10 a.m. for Glasgow. It was 2 p.m. before they got to Bowling, ten and a half miles above Greenock, in consequence of a

ripple of a head wind, and there all the passengers had to walk to Glasgow owing to the want of water, the tide having ebbed; and so late as 1815 a traveller by that steamer records that he left Glasgow in the morning, and arrived at Greenock after a seven hours' passage, three hours of which were spent lying on a sandbank at Erskine. Lighters drawing not more than 4½ ft. have been known, owing to neap tides and consequent groundings, to take six weeks to make the return voyage from Greenock to Glasgow and back; and while all but two of the first twenty steamers built on the Clyde had their engines made by Glasgow engineers—the engines of the excepted two being made by Boulton, Watt & Co., Soho—their hulls were built at Dumbarton, Port Glasgow, and Greenock.

Fly-boats for passengers, with sails and oars, were used before the introduction of steamboats, a whole day being often spent in the passage between Glasgow and Greenock.

Steam tugs for towing the lighters followed soon after the introduction of passenger steamers, and in recent years steam has been extensively applied to the lighters themselves.

Before the year 1818, none of the vessels in the foreign trade came further up the river than Greenock or Port Glasgow. Their cargoes were there discharged into lighters, which carried them to Glasgow, and at that date the largest ship belonging to either Port Glasgow or Greenock did not exceed 400 tons.

In 1821, vessels drawing 13½ ft.; in 1830, drawing 14 ft.; in 1840, 17 ft.; in 1850, 19 ft.; in 1870, 21 ft.; in 1880, 23 ft.; and last year a sailing vessel, the *Lord Charlemont*, drawing 25 ft. 1 in., came up the river, while steamers with a draught of from 23 ft. to 24½ ft. pass up and down the river almost daily, leaving Glasgow and Greenock respectively about an hour or so before high water, and passing over the navigation between these two points in about two hours.

The river, cross Channel, and other steamers of 16 ft. draught and under, leave Glasgow and Greenock respectively at any state of the tide, as the depths already given of the navigation clearly show they can do.

The towing of sailing vessels between Glasgow and Greenock by steamtugs is now nearly universal. Small sailing craft are formed into trains, and each train is towed by one tug.

Deep-draughted sailing vessels, and all the large Transatlantic and other foreign-going steamers, have a tug each to take them round the quick bends, and the largest class have generally a tug ahead and a tug astern.

The bed of the river from Glasgow to Port Glasgow is now virtually level throughout, and 7½ ft. of the 8 ft. 9 in. increased range of tide in Glasgow Harbour, and the whole present depth of from 16 ft. to 20 ft. at low-water spring tides—together, 23½ ft. to 27½ ft.—have been obtained by dredging out the bottom of the river.

The accompanying longitudinal section (Plate I.) will show more clearly than words can the enormous amount of deepening executed in the improvement of the Clyde.

As may be readily supposed, groundings in the river were of frequent occurrence in the earlier days of the river's improvements, shipowners being prone to load their vessels to the utmost capacity of the deepened river with tides and winds in their favour, making too little allowance for tides nipped by frosts or east winds. But at length the deepening has got the better of the deep loading, so that while in 1871, 59 vessels grounded between Glasgow and deep water at Greenock, two of them below the Clyde Trustees' western boundary, the registered tonnage of the largest of which was 2,069 tons, and the greatest draught 21 ft. 7 in., in 1886 only 16 vessels grounded, six below the Trustees' boundary, the registered tonnage of the largest being 3,613 tons, and the draught 24 ft. 9 in.

In 1800 the time of high water at Glasgow was two hours behind Port Glasgow; now it is only one hour.

Even so late as the summer of 1858, a float put into the river at Glasgow Bridge at the first of ebb took 537 hours, or 43½ tides, to reach Port Glasgow, a distance of 19·4 miles; while in the summer of 1881, a float under exactly similar conditions reached Fort Matilda, below Greenock, a distance of 23·5 miles, in 86 hours 20 minutes, or 7 tides; while the average of six trials made in the last-named summer was 23½ miles in 123 hours 40 minutes, or 10 tides.

Any history of the improvement of the river would be incomplete if reference were not made to the removal of Elderslie Rock, a huge vein of trap, which extends across the river a short distance above Renfrew. In the early reports on the condition of the Clyde no mention is made of this rock, but the Blawarthill Sand, one of the many shallow fords on the river, was situated where the rock was subsequently found, and in 1755 there was a depth on this sand of only 18 in. at low water, and 4 ft. 9 in. at high water.

It was not till 1854 that the existence of the rock was discovered by the grounding on it of the *Glasgow*, one of the first steamers trading between Glasgow and New York, which, while passing up the river, knocked a hole in her bottom on the rock. It was at first thought it might be a large boulder that had done the damage, but borings showed that it was rock, that it extended over an area of the bed of the river 925 ft. in length by about 320 ft. in breadth, and that it was a hard whinstone or trap dyke. From the time of its discovery till the beginning of 1869, boring from a movable stage

and by diving bell, and blasting with gunpowder, had given a minimum depth at low water springs of 14 ft. for half the width of channel, and a minimum depth of 8 ft. for the other half, the total width of the river there from bank to bank being only 410 ft., at an expenditure of upwards of £16,000; but it was not till 1880 that the removal of the rock, so as to give a uniform depth of 20 ft. at low water springs over every portion of the channel, was commenced by Colonel Beaumont with his diamond drills. In addition to the novelty of using diamond drills, there was the further novelty that the holes were bored, charged, and exploded from a floating barge, without the aid of divers; a mode of blasting subaqueous rock which had never before been adopted.

The boring was done in longitudinal belts, in sections of five rows of holes transversely, by 40 ft. long; the holes were transversely 2½ ft., and longitudinally 5 ft., apart centres, and so that the holes longitudinally would be opposite one another in each alternate row. Eight holes longitudinally were bored simultaneously, then charged and blasted, and the other four rows dealt with in the same way. When all the five rows in the section had been bored, charged, and blasted, the boring barge was shifted up stream, and commenced operations on the next 40 ft. long section, and an ordinary but powerful single ladder small bucket dredger following, lifted the broken rock, and left an open face for the next belt of holes.

It was early found that where the depth of hole was more than 10 ft. the rock was not sufficiently disintegrated to enable the dredger to clear it freely away to the bottom of the holes, and the deeper portions of the rock were therefore taken in two depths or breaks, the first depth being bored to 17 ft. at low water, blasted, and dredged.

The longitudinal belts of holes were continued from the south side, outwards, into the middle of the river, until the whole ground in the southern half was cleared away to 20 ft. at low water, the whole up and down traffic being meantime confined to the north half of the river. The whole traffic was then diverted from the north into the new south channel, which was marked by three of Pintsch's compressed gas-lit buoys, capable of burning for three months continuously. The operations were then continued northwards, until the whole depth of the river bed was cleared to 20 ft. depth.

The explosives used were dynamite, blasting gelatine, tonite, and potentite. Dynamite was found most satisfactory. Blasting gelatine proved the most powerful explosive, but when frozen was more dangerous to handle and more difficult to explode thoroughly. Tonite and potentite were found to be less powerful than dynamite, and failed to explode unless kept quite dry.

Two horizontal engines on the deck of the boring barge, supplied with steam from two boilers, drove the eight drills by a main shaft which extended the whole length of the barge.

The diamond boring tool was a steel annular ring, 2¼ in. in diameter and ½ in. thick, studded with diamonds, overlapping one another. This annular ring, or crown, was screwed on to the bottom of the boring rod, which in suitable lengths was carried inside an iron guide-tube, extending down to the bottom of the river-bed; the rod was connected at the top to a drill bar suspended from an iron diagonal framework on the barge. Rotary motion was given to the drills by means of phosphor-bronze bevel wheels, working in a frame and driven from the main shaft on deck by an ingenious arrangement of ropes and loose pulleys, which allowed for any lateral or vertical movement of the drill through rough weather, the rise and fall of the tide, and the ranging of the barge through the suction of passing steamers. The drill bar was driven at the rate of 400 revolutions per minute; and during the whole time that the boring was proceeding, water, at a pressure of 40 lbs. per square inch, was forced down through the hollow boring-rod to wash out the detritus and keep the face of the diamond crown cool. The pressure on the drill was applied by means of counter-balance weights, varied according to the hardness of the rock being bored. In the hard blue whinstone, the boring of the holes of 2¼ in. diameter proceeded at the rate of 2 ft. per hour, and 5 ft. per hour in softer stone. When the necessary depth of hole was bored, which was ascertained by sounding the hole and comparing the depth with that on a tide gauge adjoining the works, the drill rods were withdrawn, and the dynamite charges lowered through the guide-tubes into the bottom of the holes, and the tubes withdrawn. The dynamite charges were fitted with detonators and primers, and attached to each charge were electric cables, which were led up to the surface of the water. All the charges were then connected, and the shot-hole wires at either end were attached to a main cable, which was carried to the positive and negative poles of a Siemens high-tension electric exploder. The barge was then withdrawn about 60 ft. from the place of the explosion, and the row of eight holes was fired simultaneously, resulting in the displacement of something like 100 tons of rock: the only disturbance was a slight upheaval of water. The greatest amount lifted by the dredger in one day was 280 tons. A diving bell afterwards went over the ground, and removed any large stones that had been left by the dredger.

More readily to convey an idea of the amount of labour involved in the removal of the rock, it may be stated that something like 16,000 holes were bored, equal to about 90,000 lineal feet. About 110,000 tons of whinstone and boulder clay were dredged. About 76,000 lbs. of dynamite and other explosives were used without loss of life or damage to limb, and were exploded by means of about thirty-five miles of electric cable and shot-hole wire. The cost from first to last was £70,000. The whole operations were carried on in all weathers, fair and foul, without interfering in any way with the continuous day and night traffic of the river, which, during the fully five years the works extended over, was confined to the one or other half of the channel, and amounted to 180,000 vessels, with a tonnage of 33,000,000 tons, and included the

largest steamers afloat, the *City of Rome*, the *Umbria*, the *Etruria*, the Russian iron-clad *Peter the Great* being among the number.

The dredging plant of the Clyde Trustees consists of five steam dredging machines from 40 to 75-horse power each, one floating steam 10-ton digger, 18 steam hopper barges from 35 to 65-horse power nominal, one tug steamer, two diving bells, one of which is wrought by steam; 210 punts, and 81 row-boats of various sizes.

The lighting of the channel of the Clyde between Glasgow and Port Glasgow is by three light towers at Dalmuir, Rashilee, and Donald's Quay respectively, all above Bowling; by a beacon light at Longhaugh Point a mile below Bowling, and by Dumbuck Lighthouse about two miles below Bowling; by Garmoyle Lightship a mile below Dumbarton Castle, by Cardross Light a mile above the Clyde Trustees' boundary at Port Glasgow; and by seven lighted buoys on the south side of the channel between Dumbarton and Port Glasgow; the whole being lit by Pintsch's gas.

The Clyde from Port Glasgow to the sea is lit by the Clyde Lighthouses Trust, under whose charge the estuary is to the Cumbrae Heads, twenty-two miles below Greenock.

II.—Progress of the Harbour and Commerce of Glasgow.

Three hundred years ago it cannot have entered into the mind of the most sanguine and far-seeing citizen of Glasgow that his city, founded by St. Kentigern or St. Mungo in 560 A.D., would ever become one of the leading ports of Great Britain, situated as it was on a shallow, sand-choked stream, upwards of twenty miles from deep water at Greenock, and its usual port, Irvine, in Ayrshire, twenty-nine and a half miles by land from Glasgow, from which merchandise was conveyed to and fro by lighters and pack horses.

The magistrates of Glasgow, with that doggedness characteristic of Scotchmen, however, determined to have a port nearer home, and in 1658 made overtures to the magistrates of Dumbarton to purchase ground for an extensive harbour there, but these were declined on the ground that the great influx of mariners and others would raise the price of provisions on the inhabitants; they therefore, in 1662, purchased 13 acres at Newark, on which they afterwards laid out the town of Port Glasgow, built harbours, and constructed from the design of James Watt the first graving dock in Scotland, recently enlarged.

While thus fostering Port Glasgow, they still hankered after accommodation for ships at Glasgow, and in 1688 built a quay at the Broomielaw there, at the cost of £1,666 13s. 4d.

In 1755 Smeaton recommended that a dam be put across the river four miles below Glasgow, in order to secure 4½ ft. of water at all times up to this quay, and a

lock on the dam 18 ft. in the clear, and to take in a vessel 70 ft. long, or to let pass a sloop or brig of above 100 tons when there was water in the river to admit it.

The extension of the harbour synchronised with the deepening of the river, so that while in 1800 the quayage was only 382 yards long, the water area of the harbour only 4 acres, the revenue of the Clyde Trust £3,400 and the Customs revenue £427, the length of the quayage is now 10,839 yards, or 6 miles 275 yards, the water area 154 acres —fully one-half of the latter and of the total quayage having been added since the author became Engineer to the Trust—the Trust revenue £287,933, and the Customs revenue £1,012,051. The total imports and exports for the year ending June 30, 1887, amounted to 3,723,058 tons, while the registered tonnage of vessels arriving at the harbour was 3,118,515 tons.

The extension of the harbour was from Glasgow Bridge downwards. Until 1865 the sides of the river afforded sufficient ground for the extension of the quayage; in 1867 the first dock, called Kingston Dock, having 5⅓ acres of water space and 830 lineal yards of quayage, was opened; and in 1880 the second dock, by special permission of Her Majesty named the Queen's Dock, having 33¾ acres of water area and 3,334 lineal yards of quayage. Both docks are tidal.

In 1856 Messrs. Tod & McGregor, shipbuilders, Meadowside, Partick, built a graving dock 500 ft. long in connection with their yard there, which along with the yard and a patent slip are now the property of Messrs. D. & W. Henderson & Co.

In 1875 the first public graving dock, 565 ft. long, by 22 ft. 10 in. on the sill at high water spring tides, was completed by the Clyde Trustees, and another of same depth but 575 ft. in length was opened in 1886.

Messrs. Aitken & Mansel have two slips in the shipyard of which they are tenants under the Clyde Trustees, at the entrance to the Queen's Dock; and Messrs. A. & J. Inglis have a large slip in connection with their yard at Pointhouse, within the precincts of the harbour, which is now two miles in length, its western limit being the mouth of the Kelvin at Govan.

The river side and dock quays are well equipped with everything necessary for the speedy loading and unloading of vessels, including five and three-quarter miles of harbour railway on the north side and three miles on the south side, connecting with the whole railway system of the Kingdom.

The Clyde Trustees have no warehouses, but have 25¾ acres of sheds for the accommodation and protection of goods. Unlike dock companies, they do not load and

unload goods ; these duties, with their consequent profits, are left to the shipowners to perform. They, however, by means of thirty-three steam and hydraulic cranes, ranging in lifting power from 30 cwts. to 75 tons, load coals, heavy machinery, discharge ore, mast vessels, and place boilers and engines on board the majority of the numerous steamers built on the river banks in Glasgow and the neighbourhood.

Several of the largest shipbuilders and marine engineers, such as Messrs. A. and J. Inglis, the Fairfield Shipbuilding and Engineering Company (Limited), Alexander Stephen & Sons, and James and George Thomson, put the boilers, engines, &c., on board by means of shears or cranes in their own yards.

The Trustees permit shipowners to place steam cranes on the breasts of the quays at their allocated berths, and there are at present twenty-four of these in use, ranging from 40 cwt. to 20 tons in lifting power.

The author has no information as to when ferry-boats commenced to cross the harbour ; but they have now become an important means of public communication between the north and south sides of the city and suburbs, and the Clyde Trustees have at present six cross-harbour ferry passenger steamers, five of the six having fire-engines on board, for the service of the four cross ferries within the harbour limits, and two passenger, carriage, cart and horse steamers for Govan ferry. The cross-harbour passenger steamers are licensed to carry from 46 to 108 passengers. The first commenced to ply in December, 1865.

Steam was first applied to the Govan ferry in 1867, when the first steamer was put on, superseding a boat wrought by hand wheels. This steamer is of 15-horse power nominal, having single cart and carriage way in the centre, accommodates three horses and carts and fifty passengers, or 200 passengers alone, and is wrought on one chain stretched across the bottom of the river.

The second steamer, designed by the author, commenced working in 1875. It is 20-horse power nominal, has two cart and carriage ways, one on each side, passengers being accommodated in the centre. It carries eight horses and carts and 140 passengers, or 500 passengers alone. It is wrought by two chains across the river, one on the inside of each cart-way.

The Trustees have also three row ferries : one across the mouth of the Kelvin, one across the river at Meadowside, a short distance below Govan ferry, and one across the river at Whiteinch. The Renfrew Burgh authorities maintain a horse and carriage ferry across the river at Renfrew, and Lord Blantyre one at Erskine.

The number of passengers conveyed across the river at the eight ferries belonging

to the Trustees during the year ending June 30, 1888, was 7,364,813, and the gross revenue derived therefrom amounted to £13,158 15s. 6d.

The charge for crossing is one halfpenny, and eighteen single-journey tickets are sold for sixpence. In April, 1884, the Clyde Trustees established under authority of Parliament a service of passenger steamers to ply between Victoria (formerly Stockwell) Bridge and Meadowside, and these steamers, six in number, licensed to carry from 235 to 350 passengers, ply at fifteen-minute intervals between these points, calling at various intermediate stations on both sides of the harbour, the fare being one penny for the whole distance of 2½ miles. During the year ending June 30 last they carried 1,615,624 passengers, the gross revenue from which was £6,731 15s. 4d.

While in 1656 Commissioner Tucker stated that there were only twelve vessels belonging to the merchants of the Port—three of 150 tons each, one of 140, two of 100, one of 50, three of 30, one of 15, and one of 12, none of which came up to the town—the Board of Trade statistics for last year show Glasgow to be the third largest shipowning port in the Kingdom, with 1,487 vessels of an aggregate tonnage of 1,141,037, against Liverpool, with 2,350 vessels of 1,820,375 tons, and London, with 2,488 vessels of 1,156,682 tons; but if Greenock, with its 331 vessels of 229,912 tons, was classed with Glasgow, as it well might be, it would give the Clyde 1,818, of 1,370,949 tons, and thereby make it the second largest shipowning river in the Kingdom.

As to volume of trade, Glasgow, in regard to entrances and clearances of ships on foreign voyages, stands sixth in the list of British ports, with 2,324 vessels, of 2,336,958 tons, being surpassed by London, Liverpool, Cardiff, the Tyne ports, and Hull; while if the coasting traffic is included, Glasgow also stands sixth, with 17,163 vessels and 5,539,266 tons; but if Greenock were counted, the Clyde would stand fifth, with 27,067 vessels, of 7,597,341 tons.

Glasgow is the birthplace of the Allan Line, the Anchor Line, the City Line, the State Line, and the Clan Line of first-class steamers, by which constant communication is kept up with Canada, the United States, Africa, and India; while the famed Burns Line of mail steamers cross nightly to and from Belfast, in all sorts of weather, with such regularity that the town clocks of Greenock might safely be set by their arrival and departure. Aitken, Lilburn & Co.'s Lines of sailing ships to Melbourne and Sydney leave nothing to be desired. Various other lines maintain frequent communication with other colonial and foreign ports; while the connections with the English, Irish, and Continental ports are numerous and regular.

Nowhere can such a fleet of handsome and commodious river passenger steamers be seen as on the Clyde; the names of many of them have become household words for all that is luxurious and comfortable in pleasure sailing.

The first commerce of Glasgow was the curing and exporting of salmon caught in the river, and the curing and exporting of herrings brought by wherries from the West Highlands.

The union of England and Scotland, consummated March 25, 1707, though violently opposed, leading to riots of a serious character, gave to the commerce of Glasgow its first great impetus, which has continued in increased volume down to the present day, by opening up to Scotland trade with the Colonies, leading its merchants to go into shipowning on their own account, instead of, as hitherto, chartering vessels from the port of Whitehaven and elsewhere on the north-west of England, and ultimately gave them the largest share of the foreign export trade, and a monopoly of the tobacco trade of the kingdom; so that in the year 1772, out of 90,000 hogsheads of tobacco imported into Great Britain, Glasgow alone imported 49,000, and in the year preceding that of the American War of Independence the imports into the Clyde were 57,143 hogsheads, the property of 42 merchants, who realised princely fortunes.

The Declaration of Independence changed all this, and "fresh fields and pastures new" had to be sought for. Trade with the East and West Indies was opened up, and cotton-spinning started.

At this time the vast mineral deposits of the West of Scotland still lay many fathoms deep, waiting the genius of James Watt to supply the mighty power to bring them to the surface, and to raise the strong blast to fuse them into use.

The power-loom, introduced into Glasgow in 1773, and driven by a large Newfoundland dog, also waited his master hand, which was at length so well applied that in 1846 the consumption of cotton in Scotland was 119,225 bales, the greater part being absorbed in Glasgow.

All this is now altered. Little tobacco is imported direct, the consumption of cotton is much reduced, and what is used comes *viâ* Liverpool, while London has carried off the tea trade; but in place of these the imports of American and other produce in their infinite variety has largely increased in late years, and Glasgow has become a large distributing centre for the south-west of Scotland and the north of England; while trade in Spanish and other ores, and in fruit, has sprung up in recent years, which has more than made up for the loss of the tobacco, cotton, and tea.

The mineral wealth of the district in coal, iron, lime, shale oil, &c., has been largely developed; and the making and exporting of sugar machinery, locomotives, and malleable ironwork has taken such a deep root in Glasgow that it will not easily be displaced.

The Singer Sewing Machine Company have within the last few years completed the erection of large sewing machine works on the north side of the Clyde,

about six miles below Glasgow, which cover 46 acres of ground, and give employment to several thousands of men, women, and children.

In no instance have river improvement works been attended with such beneficent results, commercial, industrial, and social, as this of the Clyde, which has in recent years been indeed a gold-producing stream.

For the year ending June 30, 1887, the chief Exports from Glasgow harbour were :—

	Tons.
Ale, Beer, and Porter	32,628
Bale and Box Goods	120,958
Bricks	33,490
Castings	32,547
Cast-iron Pipes	98,171
Coal	831,356
Earthenware	10,613
Flour	28,614
Iron, Bar and Rod	70,594
Iron, Pig	191,120
Iron, Scrap	12,244
Machinery	51,743
Oatmeal	7,866
Oil (Crude Shale)	21,225
Potatoes	8,734
Railway Chairs and Sleepers	14,769
Steel	24,131
Steel Blooms	18,640
Stones	10,481
Sugar	5,244
Timber	17,025
Tubing, Malleable Iron	16,440
Wrought-iron Railway Sleepers	4,965

And the chief Imports were :—

Bacon	12,091
Bale and Box Goods	26,737
Barley	29,903
Beans	11,627
Beef	8,484
Cheese	7,077
Chrome Ore	9,025
Coal	4,070
Cotton	5,899
Eggs	14,810
Flour	209,228
Fruit	23,280

	Tons.
Hams	5,431
Hay	10,030
Herrings	9,175
Indian Corn	153,948
Iron Ore	374,826
Iron, Pig	40,761
Iron, Scrap	11,023
Linseed Oil Cake	7,847
Nitrate of Soda	7,589
Oats	27,153
Oil	17,907
Peas	28,573
Pyrites	37,341
Resin	10,392
Salt	18,608
Sand	25,062
Spirit	22,922
Stones	20,349
Sugar	42,047
Timber	87,949
Wheat	71,282

The total Exports were 1,914,450 tons, and the total Imports were 1,808,608 tons.

The total gross revenue of the Clyde Trust from July, 1752, to June 30, 1887, amounts to £7,167,281 17s. 10d., and the gross expenditure for the same period £11,622,950 2s. 9d., while the total debt due by the Trust at the latter date was £4,506,556 15s. 7d.

A few of the chief items of total expenditure may be interesting:—

General Management, Salaries, &c.	£407,750
General Expenditure, Repairs and Upkeep of Works, Damage to Fishings, &c.	596,000
Extraordinary Repairs, Parliamentary opposition	50,614
Cranes, Wages, and Repairs	92,600
Ferries, Wages, and Repair of Boats	206,500
Ground Annuals and Feu Duties	357,000
Taxes	211,770
Interest on Borrowed Money	3,418,670
Dredging Plant and repair of same	733,856
Land for Enlargement of Harbour	1,203,554
Land for Widening River	177,669
Construction of Harbour Works	1,159,523
Construction of River Works	436,700
No. 1 Graving Dock	134,867
No. 2 Graving Dock	107,784
Stobcross Docks, exclusive of land	825,212
Engineering and Surveying	20,032

The following abstract of the Revenue of the Clyde Trust for the year ending 30th June, 1887, taken from the annual printed accounts, shows the sources of the Trust's Income, and the accompanying Map of the Harbour shows the various quays, docks, ferries, &c. :—

	£	s.	d.
Dues on Vessels	66,210	5	8
Dues on Goods	162,761	16	11
Crane Dues	7,406	5	3
Weighing	1,582	0	6
Planks	1,179	5	9
Rhones	4	18	7
Water	3,569	17	7
Rents for Timber Yards and Offices	2,076	7	10
Quay Rents	121	9	0
Harbour Tramways	974	13	0
Graving Docks	7,920	2	10
Coaling and Mineral Cranes, Queen's Dock	5,658	13	10
Waiting-Rooms	8	2	2
Lower Stages of River	1,439	19	9
Swinging Buoys in Gareloch	25	12	3
Ferries—Harbour	8,007	16	9
,, Govan	3,578	15	4
Up and Down Passenger Steamers	5,613	15	2
Rents	7,859	14	10
Miscellaneous	1,934	4	9
	£287,933	17	9

III.—Rise and Progress of Shipbuilding on the River and its Tributaries.

Of the numerous industries that flourish on the banks of the busy Clyde, the palm must be given to shipbuilding and marine engineering. These, as much as its commerce, have spread its fame over every portion of the habitable globe; its floating palaces traverse every sea. The Clyde took the lead in introducing the steamboat to the Old World, which in the short space of seventy-five years has revolutionised the carrying trade of the world, and brought about that commercial intercourse between nations which has so vastly increased the comfort and happiness of the whole human race. The application of James Watts's inventions to steam navigation by Patrick Miller, William Symington, and Henry Bell, and the improvement of the Clyde, most singularly coincided, and the further development of both still go hand in hand.

But for the continuous deepening of the river, while there might possibly have been a *Comet*, there could have been no *Iona*, no *Columba*, no *Lord of the Isles*, no *Livadia* with its 153 ft. beam, no *Umbria*, no *Etruria*, no *City of New York*, launched

from its banks above Dumbarton. So far, however, as depth of water was concerned, shipbuilding was always possible at Dumbarton, Port Glasgow, and Greenock.

By 1839, four shipbuilding yards had been established at Glasgow within the limits of the present harbour: Tod & Macgregor's and Thomas Wingate & Co.'s on the south side—the latter of whom engined the *Sirius*, built at Leith in 1837, the first British steamer to cross the Atlantic—and Robert Napier's, and Barclay, Curle & Co.'s, on the north side: some few years thereafter yards were established on the north side by Stephen & Sons, and on the south side by Smith & Roger, now the London and Glasgow Engineering and Iron Shipbuilding Company, Limited, and Napier & Sons, the senior partner of whose successors under the same name, Dr. A. C. Kirk, introduced, in 1874, while with John Elder & Co., the triple expansion engine, which has effected so great an economy in the consumption of fuel as to enable cargo steamers to be financially successful in trading to the most widely distant ports.

Following the three last named firms, Charles Connell & Co. on the north, and James and George Thomson, who had previously confined themselves to marine engineering, and Hedderwick & Co. on the south side, opened yards within the limits of the harbour.

Tod & Macgregor were the first to be crushed out of the Harbour, and in 1846 they removed to Meadowside, on the west bank of the Kelvin, at its junction with the Clyde. Wingate & Co. followed suit, to Whiteinch.

About twenty-five years ago, Messrs. A. and J. Inglis added shipbuilding to their former business of marine engineers, by constructing their yard at Pointhouse, at the mouth of the Kelvin, opposite Tod & Macgregor's; and about twenty years ago, Messrs. Randolph & Elder, to whom belong the merit of introducing in 1854 the compound engine into steam vessels, did the same by laying out at Fairfield, Govan, one of the most extensive shipbuilding yards and marine engineering works in the Kingdom, now the property of the Fairfield Engineering and Shipbuilding Company, Limited.

One by one, all but Napiers', the London and Glasgow's, and Hedderwick & Co.'s yards on the south, and Stephen & Sons', now Aitken and Mansel's, and A. and J. Inglis' on the north side of the Harbour, have been absorbed in quay extensions.

Barclay, Curle & Co. went down the river to Whiteinch; Stephen & Sons to Linthouse, adding engineering to their business; Connell & Co. to Scotstoun; and James and George Thomson to the already far-famed yard at Clydebank, to which they have within the last three years transferred from Glasgow the whole of their

marine engine works, and where, like the Fairfield Company, they have a large and well-equipped tidal basin for fitting out the vessels they build.

The engine works of Napier & Sons; the London and Glasgow Engineering and Iron Shipbuilding Company; A. and J. Inglis; Barclay, Curle & Co., and W. and D. Henderson & Co., are still in the city adjacent to the north side of the harbour; and the following well-known firms in Glasgow confine the whole of their attention to marine engine work:—Dunsmuir & Jackson; Hutson & Corbett; Kemp; William King & Co.; Lees, Anderson & Co.; Muir & Caldwell; Muir & Houston; Ross & Duncan; D. Rowan & Son; John and James Thomson; and Walker, Henderson & Co.

There are 43 shipbuilding yards in what may be termed the Clyde district: one yard, that of T. B. Seath & Co., at Rutherglen, three miles above Glasgow, where have been built many of the beautiful steam yachts and pleasure steamers which ply on our English lakes, on our Scotch lochs, and on foreign waters; one at Blackhill, on the Monkland Canal; one at Maryhill, on the Forth and Clyde Canal; five within the limits of the harbour; one at Partick, immediately below these limits; two at Govan, four at Whiteinch, one at Scotstoun, two at Renfrew, one at Yoker, two in the burgh of Clydebank, four in Paisley, one at Bowling, five at Dumbarton, eight at Port Glasgow, and four at Greenock.

The first iron vessel built in Scotland was the *Vulcan*, by Thomas Wilson, at Faskine, on the Monkland Canal, about eleven miles from Glasgow. It was launched on May 28, 1818, and until within the last fifteen years was still engaged in carrying coal from the Forth and Clyde Canal to ports on the Clyde.

To England, however, belongs the honour of launching, in 1821, the first iron steamer, the *Aaron Manby*, built at Horsley.

The first iron steamer built on the Clyde was the *Aglaia*, in 1827, for passenger traffic on Loch Eck; and the first to ply on the Clyde was the *Fairy Queen*, built at the old Basin Foundry, Glasgow, about 1½ mile from the river, to which it was brought bodily and launched in 1831.

The use of iron for shipbuilding did not, however, become general till about 1847. Now steel is every year more and more displacing it, on the Clyde at least, as the following table will show at a glance:—

	1881.	1884.	1885.	1886.	1887.
	Tonnage.	Tonnage.	Tonnage.	Tonnage.	Tonnage.
Steel	70,000	146,500	90,200	122,243	160,749
Iron	260,000	150,500	103,800	53,191	32,000
Wood...	1,000	607	520	668	360

The following is a list of the first twenty steamers built on the Clyde, with dimensions, builders' and engineers' names, and how disposed of as at the end of 1816 :—

No.	Name.	When Launched.	Length of Keel.	Breadth of Beam.	Carpenter's Name and Residence.	Size of Engine.	Engine Maker's Name and Residence.	How disposed of.
			ft.	ft. in.				
1	Comet	June 1812	38	11 6	J. Wood & Co., Port Glasgow	3-h.p.	J. Robertson, Glasgow	Now plying on Firth of Forth.
2	Elizabeth	Nov. 1812	40	12	J. Wood & Co., Port Glasgow	10-h.p.	J. Thomson & Co., Tradestown, Glasgow	Went to Liverpool in 1814.
3	Clyde	Feb. 1813	68	14	J. Wood & Co., Port Glasgow	10-h.p.	J. Robertson, Glasgow	Plying on the Clyde.
4	Glasgow	Sep. 1813	60	15	J. Wood & Co., Port Glasgow	14-h.p.	J. Robertson, Glasgow	Plying on the Clyde.
5	Trusty	Feb. 1814	65	16	J. Denny, Dumbarton	10-h.p.	G. Dobbie, Tradestown, Glasgow	Carrying goods on the Clyde.
6	Princess Charlotte.	Mar. 1814	65	10 6	J. Munn, Greenock	2 eng. ea. 4-h.p.	Boulton, Watt & Co., Soho	Laid up on the Clyde
7	Industry	May 1814	65	16	Munn, Fairlie	10-h.p.	G. Dobbie, Tradestown, Glasgow	Carrying goods on the Clyde.
8	Prince of Orange ..	June 1814	64	12	J. Munn, Greenock	2 eng. ea. 4-h.p.	Boulton, Watt & Co., Soho	Plying on the Clyde.
9	Argyle, 1st	June 1814	72	14 6	A. Martin & Co., Port Glasgow	14-h.p.	J. Cook, Tradestown, Glasgow	Went to London in May, 1815.
10	Margery	June 1814	56	12	J. Denny, Dumbarton	10-h.p.	J. Cook, Tradestown, Glasgow	Went to London in Nov., 1814.
11	Britannia	Jan. 1815	80	16 8	J. Hunter, Port Glasgow	24-h.p.	Dun. M'Arthur & Co., Camlachie, Glasgow	Plying on the Clyde.
12	Dumbarton Castle.	Feb. 1815	84	18 8	J. Denny, Dumbarton	30-h.p.	Dun. M'Arthur & Co., Camlachie, Glasgow	Plying on the Clyde.
13	Caledonia	April 1815	86	15	J. Wood & Co., Port Glasgow	2 eng. ea. 18-h.p.	Greenhead Foundry Company, Glasgow	Went to London in July, 1816.
14	Greenock	May 1815	80	16 8	J. Denny, Dumbarton	32-h.p.	Dun. M'Arthur & Co., Camlachie, Glasgow	Went to Ireland, and then to London, in May, 1816.
15	Argyle, 2nd ..	July 1815	72	15	J. Wood & Co., Port Glasgow	20-h.p.	Greenhead Foundry Company, Glasgow	Plying on the Clyde.
16	Waterloo	Jan. 1816	72	16	J. Hunter, Port Glasgow	20-h.p.	J. Cook, Tradestown, Glasgow	Plying on the Clyde.
17	Neptune	Feb. 1816	68	15 5	J. Wood & Co., Port Glasgow	20-h.p.	Dun. M'Arthur & Co., Camlachie, Glasgow	Plying on the Clyde.
18	Lord Nelson ..	Feb. 1816	71	16	J. Wood & Co., Port Glasgow	20-h.p.	Greenhead Foundry Company, Glasgow	Plying on the Clyde.
19	Albion	Mar. 1816	73	16	J. Wood & Co., Port Glasgow	20-h.p.	J. Cook, Tradestown, Glasgow	Plying on the Clyde.
20	Rothesay Castle ..	April 1816	76	16 6	J. Denny, Dumbarton	34-h.p.	Dun. M'Arthur & Co., Camlachie, Glasgow	Plying on the Clyde.

The amount of tonnage built on the Clyde twenty-nine years ago was only 35,700 tons. The following Table gives the number and tonnage of vessels built in 1883, 1885, 1886, 1887 :—

	1883.		1885.		1886.		1887.	
	Vessels.	Tons.	Vessels.	Tons.	Vessels.	Tons.	Vessels.	Tons.
Steamers.								
War vessels ...	2	5,048	37	5,647	14	16,579	3	10,040
Paddle	26	13,446	15	4,899	22	13,601	24	13,754
Screws (steel) ...	208	316,202	80	52,188	48	69,002	121	105,959
Do. (iron) ...				14,400	19	4,855	7	1,571
Hoppers... ...	19	7,309	14	8,106	4	2,498	33	12,022
Dredgers ...								
Sailing Vessels.								
Steel	42	64,156	17	22,538	17	19,799	10	17,850
Iron			55	81,927	26	46,113	10	19,191
Wood	2	380	4	284	8	597	1	102
Barges	103	7,652	6	2,140	12	734	62	10,738
Yachts.								
Steam	6	1,300	11	2,168	10	2,123	14	1,525
Sailing	5	201	6	226	13	71	10	357
	413	415,694	245	194,525	193	175,972	295	193,109

In 1883 the tonnage built was the largest on record—415,694 tons—and, with acknowledgments to *The Scotsman* newspaper, the Author is pleased to be able to give in the following two Tables the output of each builder in steam and sailing classifications for the years 1883 and 1887 respectively :—

1883.	Steam Vessels.		Sailing Vessels.		Total.	
	No.	Tons.	No.	Tons.	No.	Tons.
John Elder & Co.	12	40,093	1	20	13	40,113
Russell & Co....	9	1,848	19	28,763	28	30,611
R. Napier & Sons	6	23,873	...	...	6	23,873
A. Stephen & Sons	11	22,450	...	...	11	22,450
W. Denny & Brothers	10	22,240	...	...	10	22,240
London & Glasgow Company	9	19,793	...	...	9	19,793
D. & W. Henderson & Co.	7	14,724	72	2,990	79	17,714
Scott & Co.	9	17,685	...	...	9	17,685
Aitken & Mansel	8	16,890	...	...	8	16,890
R. Duncan & Co.	6	4,244	12	12,335	18	16,579
Barclay, Curle & Co....	7	13,214	1	1,986	8	15,200
J. & G. Thomson	7	15,010	...	...	7	15,010
A. & J. Inglis...	8	14,741	...	...	8	14,741
A. M'Millan & Sons	3	4,376	5	8,751	8	13,127
Caird & Co.	7	12,258	...	...	7	12,258
Connell & Co.	5	12,002	...	...	5	12,002
Dobie & Co.	9	7,913	1	1,367	10	9,280
Napier, Shanks & Bell	3	8,796	1	298	4	9,094
W. B. Thompson	4	6,545	1	2,278	5	8,823
Blackwood & Gordon	8	8,616	1	25	9	8,641
Lobnitz & Co.	13	6,647	...	...	13	6,647
H. Murray & Co.	6	6,645	...	...	6	6,645
J. Reid & Co....	2	994	6	5,752	8	6,746
Murdoch & Murray	8	6,308	...	...	8	6,308
H. M'Intyre & Co.	10	6,262	...	...	10	6,262
R. Steele & Co.	4	4,015	2	1,805	6	5,820
D. J. Dunlop & Co.	7	5,559	...	...	7	5,559
Burrell & Sons	5	4,255	...	...	5	4,255
W. Hamilton & Co.	3	1,828	1	2,093	4	3,921
M'Arthur & Co.	12	1,438	3	1,178	15	2,616
W. Simons & Co.	6	2,544	...	...	6	2,544
Birrell, Stenhouse & Co.	1	1,439	1	1,081	2	2,520
T. B. Seath & Co.	9	1,681	7	630	16	2,311
Fullerton & Co.	7	2,212	...	...	7	2,212
Campbeltown S. Company	4	1,826	...	...	4	1,826
Abercorn S. Company	4	851	1	25	5	876
Scott, Bowling	3	846	...	...	3	846
Murray Brothers	3	403	...	...	3	403
Troon S. Company	...	...	2	379	2	379
Swan & Co.	...	...	4	285	4	285
M'Knight & M'Creadie	1	237	...	...	1	237
W. S. Cumming	2	80	6	100	8	180
W. Fyfe	1	65	5	47	6	112
M'Adam	1	10	...	...	1	10
M'Allister	1	50	...	...	1	50
Total	261	343,506	152	72,188	413	415,694

1887.	Steam Vessels.		Sailing Vessels.		Total.	
	No.	Tons.	No.	Tons.	No.	Tons.
Russell & Co....	6	9,585	9	17,457	15	27,042
A. Stephen & Sons	8	18,884	2	4,031	10	22,915
W. Denny & Brothers	15	12,824	16	7,124	31	19,948
D. and W. Henderson & Co.	5	14,297	2	155	7	14,452
Fairfield Shipbuilding Company	6	13,228	...	...	6	13,228
Caird & Co.	2	12,525	...	...	2	12,525
Lobnitz & Co.	28	10,000	...	...	28	10,000
R. Napier & Sons	2	8,800	...	...	2	8,800
J. and G. Thomson	3	8,139	...	...	3	8,139
C. Connell & Co.	2	4,492	2	3,348	4	7,840
R. Duncan & Co.	2	3,975	2	3,688	4	7,663
A. M'Millan & Sons...	5	6,275	2	200	7	6,475
John Reid & Co.	4	2,217	3	2,761	7	4,978
A. and J. Inglis	4	4,615	...	...	4	4,615
Barclay, Curle & Co.	...	...	3	4,475	3	4,475
London and Glasgow Company	1	3,455	...	...	1	3,455
Aitken & Mansel	1	2,819	...	...	1	2,819
Alley & M'Lellan	9	1,325	13	621	22	1,946
Birrell, Stenhouse & Co.	...	...	1	1,734	1	1,734
Napier, Shanks & Bell	...	...	4	1,680	4	1,680
Simons & Co....	3	1,550	...	...	3	1,550
Scott & Co.	3	1,112	...	...	3	1,112
D. J. Dunlop & Co.	3	554	2	200	5	754
J. M'Arthur & Co.	2	580	...	...	2	580
Blackwood & Gordon	2	550	...	...	2	550
Murray Brothers	3	515	...	...	3	515
J. Fullerton & Co.	1	432	6	80	7	512
M'Knight & Co.	2	399	...	...	2	399
Abercorn Company	5	376	...	...	5	376
W. S. Cumming	4	123	9	244	13	367
Fleming & Ferguson...	1	250	...	...	1	250
Mechan & Sons	47	245	...	...	47	245
Fife & Sons	...	...	5	196	5	196
M'Gill & Co.	2	187	...	...	2	187
Scott & Co., Bowling	2	169	...	...	2	169
T. B. Seath & Co.	1	120	...	...	1	120
Ailsa Company	2	42	1	78	3	120
T. Orr...	11	66	7	50	18	116
J. and J. Hay	...	...	1	80	1	80
J. Thomson	3	56	..	...	3	56
Ross & Duncan	1	40	1	26	2	66
Murdoch & Murray	1	50	...	...	1	50
Other Builders	...	...	2	10	2	10
	202	144,871	93	48,238	295	193,109

For more detailed information regarding the earlier river, home, and foreign going steamers, the Author begs to refer the Institution to a book called " The Clyde from its Source to the Sea," just published by Mr. W. J. Millar, the respected Secretary of the Institution of Engineers and Shipbuilders in Scotland. See also Minutes of Pro-

ceedings Institution of Civil Engineers, May 6, 1873; "The River Clyde," by James Deas, 1876; "Lectures on Naval Architecture and Marine Engineering," Glasgow Naval and Marine Exhibition, 1880-81; "The Clyde," by James Deas, 1884; and "Pollock's Dictionary of the Clyde," 1888.

The most recent development of Clyde-built steamers is the beating of the record; the Spanish torpedo catcher *Destructor*, and the Spanish cruiser *Reina Regente*, both built and engined by J. & G. Thomson, Clyde-bank, making an average of 22·6 knots and 20·6 knots respectively per hour on their trials in 1886 and 1887, over the measured mile; the Cunard Company's *Etruria*, built and engined by John Elder & Co., outward to New York in the end of May and beginning of June last, from Roche's Point, Queenstown, to Sandyhook Bar in 6 days 1 hour 47 minutes corrected time, and inward between July 7 and July 14 in 6 days 4 hours 50 minutes; the Union Company's *Athenian*, built by Aitken & Mansel, but re-engined by Messrs. T. Richardson & Sons, of West Hartlepool, about the same period, from Capetown to Plymouth in 17 days 9 hours 10 minutes, including 5 hours and 5 minutes' detention; and the Channel mail steamer *Princess Henrietta*, built and engined by W. Denny Bros., in June last on trial 21·1 knots, and Ostend to Dover, over sixty miles, in 2 hours 55 minutes.

IV.—Short Description of Other Harbours on the River.

A description of these ports would require a separate paper, and written by one with more local and special knowledge of them than the Author, to do them justice, so a few words on each must suffice.

Renfrew, about five miles below Glasgow Bridge, comes first in order. A Royal burgh, its proximity to its great neighbour has overshadowed it; from time to time its authorities have made laudable efforts to give it a harbour, but have as yet had to be content with an extension of the quayage on the town side of a burn called the Pudzeoch.

Paisley, the next in order, situate on the River Cart about three and a half miles from the junction of that river with the Clyde, is now a thriving thread spinning, corn flour producing, shawl manufacturing, shipbuilding, and general engineering town. It allowed Glasgow to take the lead in river improvement, in former years got more than one Act of Parliament to deepen, straighten, and widen its river without much good result, but under an Act passed in 1885 the quayage at Paisley is being largely extended, and the river is being deepened to 18 feet below high water of spring tides.

Bowling Harbour comes third, about eleven miles below Glasgow. It has a tidal basin of 12 acres, the joint property of the Clyde Trustees and Caledonian Railway

Company, used by the latter in connection with the Forth and Clyde Canal, and chiefly used by the former in the laying up for the winter of the extensive fleet of passenger steamers plying in summer on the waters of the Clyde and adjoining Lochs.

Here, side by side, may be seen, dismantled and silent, the famous *Iona*, *Columba*, *Lord of the Isles*, and many other river steamers which during the summer months are crowded with tourists from all parts of the world, who view with admiration the enchanting scenery of the Western Highlands.

Dumbarton.—The present authorities, inspired with much broader views on the harbour question than were their predecessors of 1658, in 1881 carried a Bill through Parliament for the improvement of the river Leven, and the providing of increased quay accommodation, but, beyond some deepening, not much has yet been done.

Port Glasgow.—The old harbours were acquired by the municipal authorities of that port, in 1864, from the magistrates of Glasgow, on payment to the latter of 5s. per £ on the amount of debt on them. A considerable amount of iron ore is discharged there and sent to the various ironworks in the West of Scotland. The harbour accounts for the year ending June 30, 1887, give the receipts as £4,868.

Greenock, Glasgow's greatest rival and former superior, and the birthplace of James Watt, has in recent years, through the enterprise of its leading men, been engaged in harbour extension of an important character, chiefly in the construction of the James Watt Dock, which has unfortunately led to a serious crippling of its harbour finances in consequence of the shipping trade of Glasgow refraining from making use of the accommodation it affords, as the shipping trade of London has declined the accommodation recently placed at its disposal at Tilbury, near the mouth of the Thames.

The harbours of Greenock have an aggregate water area of 52 acres, and there are three public and two private graving docks.

Sugar importing and refining, timber importing, and shipbuilding and marine engineering form the staple industries of the town, and the shipbuilders and marine engineers higher up the river find in the shipbuilders and engineers of the town keen, and often successful, competitors in the obtaining of contracts.

The revenue of the Harbour Trust for last year was £54,859, with a registered tonnage inwards of 231,705 tons, and outwards of 97,510 tons.

The natural Clyde begins at Greenock, where the artificial Clyde terminates, and the panorama from thence to the Atlantic is one of exquisite beauty, and must be seen

to be fully appreciated: the serrated peaks of the Argyleshire hills rising in their sublimity towards heaven on the north, the island of Bute and the two Cumbraes guarding the entrance from the sea; while still farther seaward, Goatfell, in Arran, rears its lofty head proudly to the sky, and away in the far distance, in mid-ocean, stands Ailsa Craig in its lonely isolation

The numerous watering-places, with their infinite variety of architectural designs, close-shaven lawns, and expanses of foliage, which fringe both sides of the estuary, in some places continuous for miles; the white-winged yachts innumerable skimming its surface in all directions, the outward or inward bound Atlantic liner ploughing its way through its azure waters, the full-sailed Indiaman gliding slowly along, and ever and anon the swift passenger steamer dashing from pier to pier, make in the summer months a scene which, once gazed on, can never be forgot.

Admiral Sir John Hay (Vice-President) moved a vote of thanks to Mr. Deas (who was unavoidably absent) for his valuable paper. The motion was unanimously carried.

COPPER STEAM PIPES FOR MODERN HIGH-PRESSURE ENGINES.

By W. Parker, Esq., Chief Engineer Surveyor Lloyd's Register of British and Foreign Shipping; Member of Council.

[Read at the Thirtieth Session of the Institution of Naval Architects, July 25th, 1888; the Right Hon. the Earl of Ravensworth in the Chair.]

As might have been expected, the disastrous explosion of the main steam pipe and consequent loss of life that occurred on board the Royal Mail steamer *Elbe* in September last, and a similar explosion on board the North German Lloyd's mail steamer *Lahn*, have led to investigations as to the cause of these accidents; and, further, the whole subject of the manufacture of copper steam pipes has been considered generally, and experiments carried out with the view of ascertaining the behaviour of the different kinds of commercial copper under various conditions of treatment and at various temperatures. A summary of the investigations and the results of these experiments will not, I think, be without interest to these meetings.

The S.S. *Elbe* was built in 1870 by Messrs. J. Elder & Co., and fitted with ordinary compound engines. In February of last year she was placed in the hands of Messrs. Oswald, Mordaunt & Co., of Southampton, for the purpose of being fitted with new boilers to work at a pressure of 150 lbs. per square inch, and of having her compound engines converted into triple expansive ones. This work was completed, and the vessel was running her official trial in Stokes Bay, when the main steam pipe abreast of the after boilers burst, and all in the stokehole at the time, numbering eleven persons, were killed by the sudden outrush of steam.

The S.S. *Lahn* is a new vessel built by the Fairfield Shipbuilding and Engineering Company last year. In March last, while on her second voyage across the Atlantic, her steam pipe burst in a somewhat similar manner, but the loss of life was less in this instance than in the case of the *Elbe*.

It was natural to suppose that the bursting of copper steam pipes, such as those of the *Elbe* and the *Lahn*, would be found to be attributable to defective

workmanship or material, and that due care had not been exercised in the manufacture of the pipes; but these investigations go to show that elements of very serious danger enter into the ordinary methods of making brazed copper pipes, especially when intended for high pressure steam.

The steam pipe which exploded on board the *Elbe* was $9\frac{3}{8}$ in. diameter inside, and 6 ft. 6 in. long, the thickness of the copper was ·276 of an inch, corresponding to No. 2 Imperial wire gauge; it was brazed in the usual manner, with a lapped joint, and to all appearance seemed a well-made pipe. The copper had been obtained from a first-class manufacturer in Birmingham, and analysis has shown it to be chemically of the best quality.

The pipe itself had been tested by hydraulic pressure on two occasions, once for the satisfaction of the builders to a pressure of 300 lbs. per square inch, and a second time by the owner's representative to 350 lbs. per square inch. These tests had been sustained in a perfectly satisfactory manner, and so far as could be judged, every care had been exercised by the makers to produce as good a piece of workmanship as possible.

Test pieces were cut from the exploded pipe and the copper away from the locality of the brazing was found to have an ultimate tenacity of 33,000 lbs. per square inch, with an elongation before fracture of 33 per cent. in a length of 5 in., so that the bursting pressure for this pipe, in its cold state, should have been about 1,940 lbs. per square inch, being thirteen times the working pressure, or, taking the actual thickness of the copper at the fracture as measured after the explosion, and which was found to be $\frac{3}{16}$th of an inch, the pipe should still have borne an ultimate pressure of 1,220 lbs. per square inch, or 8·8 times the working pressure.

In order to ascertain the actual strength of the portions of the pipe adjacent to the exploded part, a piece of the pipe, about 30 in. long, was cut from the portion still intact of the length which exploded, and two other similar pieces were prepared from the next adjoining length of pipe. These short pieces were fitted with flanges and tested to destruction by hydraulic pressure, and in each case the pipe burst in exactly the same way, namely, through the copper near and parallel to the brazed seam, commencing near to one of the flanges.

The pieces taken from the same length where the explosion had occurred, gave way under a hydraulic pressure of 780 lbs. per square inch, the fracture exhibiting a granular and in part a discoloured appearance.

Of the two pieces cut from the next adjoining length of pipe, one burst at 600 lbs. per square inch with the same granular and partly discoloured fracture, as if the metal had been injured or partially cracked through during the operation of brazing; and the other burst at 1,140 lbs. per square inch, the fracture being granular but not discoloured.

This great diversity in the bursting pressures for pipes of the same dimensions and material, and the similarity in the character and position of the fracture in each case, together with the fact that the pressure at which the strongest of these lengths burst was still not more than five-eighths of the calculated bursting pressure, seemed clearly to indicate that the material had been injured in the neighbourhood of the seam by the operation of brazing.

Some very careful experiments to ascertain the effect of increased temperatures upon sheet copper were made by the Franklin Institute in America as long ago as 1837, when strips of copper were pulled asunder in a properly designed machine at temperatures ranging from 122 degrees to 1,332 degrees Fahr., and, as will be seen by the following table, the falling off in strength as the temperatures increased was very considerable, until at 1,332° F., or a bright red heat, the tenacity was nil.

Experiments made at the Franklin Institute, America, in connection with an Investigation into the Strength of Boilers.

Temperature above 32°.	Diminution of Strength.	Temperature above 32°.	Diminution of Strength.
90°	0·0175	660°	0·3425
180°	0·0540	769°	0·4389
270°	0·0926	812°	0·4944
360°	0·1513	880°	0·5581
450°	0·2046	984°	0·6691
460°	0·2133	1,000°	0·6741
513°	0·2446	1,200°	0·8861
529°	0·2558	1,300°	1·0000

These results were substantially corroborated by a series of experiments made by Dr. Kirk and myself after the *Elbe* explosion.

From the Table it will be seen that at 360° F., or the temperature of steam of 150 lbs. pressure, copper has about 15 per cent. less tensile strength than when cold. But allowing for this falling off in tenacity, the steam pipe of the *Elbe* at 150 lbs. steam pressure should still have had a factor of safety of 8½.

Carefully examined through a microscope, the difference in the structure of the copper in the neighbourhood of the brazing where the exploded pipe and those afterwards tested gave way, and the structure in that part of the pipe away from the brazing

was very marked, and was clearly to be ascribed to the heating of the copper during brazing.

Test pieces were cut from the pipe near to the brazed seam where the rent had occurred, and it was found that whereas the copper from other parts of the pipe showed a tenacity of 33,000 lbs. per sq. in. with an elongation of 33 per cent. in 5 ins. and 59 per cent. contraction of area as recorded above, in these pieces the tenacity was only 24,418 lbs. per sq. in., the elongation only 4·6 per cent., and the contraction of area at the fracture only 13 per cent. This result was amply confirmed by testing other strips cut from the same locality; they each showed that the copper near the brazing had lost its ductile qualities and much of its tenacity.

In order to obtain further information on this point, the following experiments were made :—

1. A strip of good copper was cut from a sheet and bent and broken cold.

2. A similar piece was raised to a heat above that necessary for brazing, when it became red short, and broke with its own weight.

3. A piece was raised to the same bright heat as No. 2, allowed to cool, and then broken cold.

4. A piece was raised to the above brittle heat, at which it was partially broken through, then allowed to cool, and the fracture completed when cold.

The appearances of these fractures were very interesting, as may be seen in the specimens on the table : the first had the fibrous silky appearance of a good copper; in the second piece the fracture was coarse and blackened by the heat; but the third specimen seemed to have almost completely regained its tenacity and ductility on cooling, the copper in its normal state having a tenacity of 35,212 lbs. per square inch, with an elongation of 40 per cent. in 5 in., and a contraction of area at the fracture of 39·9 per cent.; and the third specimen, although it had been raised to a blistering heat, was, when cold, found to have a tenacity of 31,337 lbs. per square inch, with an elongation and contraction of area at fracture practically the same as the normal copper, which would appear to show that, although the copper should be over-heated in brazing, if not otherwise injured its qualities will be substantially regained on cooling.

The fourth piece was partially broken while hot, and the appearance of that part of the fracture was discoloured by the action of the heat, but the part that was allowed to cool had its ductility restored, and afterwards broke with a bright fracture. This experiment was repeated a number of times, with similar results, and the fractures corresponded *exactly* in appearances not only with that of the exploded pipe, but also with those of the *other pipes* which were experimented upon, and which burst at pressures of 600 and 780 lbs. per square inch respectively.

The only difference in these fractures was the depth to which the partial crack, as shown by discoloration, had extended.

In this manner the exact appearance of the fractures of the exploded pipe, and of those experimental pieces which burst at the low pressures, was *reproduced artificially* by burning the copper and treating it in the way described.

From this it will be seen that, should a copper pipe be over-heated during the brazing operation, and seeing that the metal becomes perfectly brittle at not much above the brazing heat, the pipe might accidentally be cracked when in this brittle condition; and, although the section of metal still remaining intact might be sufficient to sustain the cold water test pressure, yet the hot steam and accompanying strains might develop and deepen the crack, and the pipe ultimately give way at the working pressure.

This I consider to be the true explanation of the explosion of the *Elbe's* steam-pipe, and also that of the S.S. *Lahn.*

A serious element of danger is thus shown to exist in the present practice of brazing large, heavy copper pipes intended to be subjected to the high pressures now so common. It is generally admitted that welds or brazed joints in any material must possess certain elements of uncertainty, and the above experiments show this uncertainty to be greatly increased in the case of copper worked over a fire.

How to eliminate these elements of danger becomes an important question. Various alternatives suggested themselves, as, for instance, that the copper might be worked cold and the joint made by a riveted seam, that brazed pipes might be served with wire or have strengthening bands fitted at short intervals (both of which systems I find are now resorted to), or that steel pipes might be used, the seam being riveted.

While these points were under consideration, I had brought to my notice by Mr. W. Elmore a method of making copper pipes of any required diameter, length, or thickness by electro-deposition, and I was instructed by the Committee of Lloyd's Register to proceed to Mr. Elmore's works and witness the operation of making these pipes, with a view to reporting thereon for the information of the Committee. The process is briefly as follows:—A mandril is surrounded by ordinary unrefined Chili bars arranged upon strong supporting frames in a depositing tank of sulphate of copper, and the copper is dissolved or decomposed, as will hereafter be explained, and is deposited in the form of pure copper on the revolving mandril, leaving the copper in the form of a shell or pipe, of any thickness required, fitting closely to the mandril. When the required thickness has been deposited, the pipe and mandril are exposed to the action of hot air or steam, then the copper expanding more than the iron admits of the mandril being drawn, leaving the copper in the form of a pipe, without a seam,

perfectly round and true both internally and externally; or the pipe may be expanded or made larger by rolling or other mechanical means, and then the mandril withdrawn.

The deposition of copper by electricity is not at all new. It has been in use for years for electrotyping purposes, and for separating copper from its impurities, and particularly for extracting gold and silver. But copper thus refined is wanting in cohesive properties, and without some means of increasing its density, which would give to it, at the same time, both tenacity and ductility, it would in such a form be useless for mechanical purposes, and the ingenious manner in which this difficulty is overcome by the present process constitutes its most important feature.

A burnisher or planisher, composed of a small square piece of agate, being the hardest and smoothest substance suitable and available, is supported upon proper arms and levers, and the agate is allowed to press lightly upon the surface of the copper on the revolving mandril. The burnisher is caused to traverse from end to end of the mandril by means of a leading screw at any required speed. After it has traversed the whole length of the mandril, it is automatically reversed, and commences its journey backwards. The speed of the revolving mandril and the speed of the traversing burnisher is so adjusted or arranged that the whole surface of the copper is acted upon by the burnisher, the result being that every thin film of copper deposited upon the mandril must be separately acted upon, burnished and compressed into a dense and cohesive sheet of pure copper possessing a great amount of tenacity and ductility, as will be seen from the results of the experiments and tests which I have made, and which will be referred to further on. The impurities or dross fall to the bottom of the tank in the form of mud, and when washed, dried and smelted in a crucible, the gold, silver, &c., contained therein can be easily separated. In fact, during the operation of refining copper from the rough Chili bars, the finished article is automatically produced in the form of a pipe, and all the impurities are extracted and can be collected.

While I was present at the works of Mr. Elmore, the patentee of this process, four pipes were made. The mandrils had been revolving in the baths for about 170 hours, and the copper in this length of time had reached a thickness of ·198 in. The pipes were taken off the mandrils in my presence, and the ends of the pipes cut off, so as to present a portion of the pipes acted upon by the burnisher. The remaining portion, or rough ends, shows the nodules, or rough copper, not acted upon by the burnisher, which is in a completely brittle condition. This will be seen by the specimen.

It is well known that the structure of ordinary electro-deposited copper is purely crystalline, and easily disruptured under stress. The adjoining faces of the crystals, of which the whole mass is composed, appear under the microscope to be separated from each other, and have very slight cohesive power.

In order to show the effect of the burnisher upon the material, I have had the structure of specimens of pieces of copper magnified under a microscope and then

photographed.* No. 1 photo is taken from an ordinary piece of cast copper. No. 2 is taken from a rolled bar of copper. The difference in these two structures is very perceptible, and plainly shows the effect of work in the shape of rolling. No. 3 shows the structure of a piece of ordinary deposited copper not burnished, and No. 4 shows the structure of a piece of copper one-third unburnished and two-thirds burnished. From these photos it can plainly be seen to what extent the crystals are reduced in size, and the cohesive power of the material increased.

To describe more in detail how the decomposition of the unrefined copper is effected, and how the deposit takes place, I may state that the unrefined Chili bars are cast into slabs of the required length of the pipe, and these are arranged longitudinally in a wooden tank, in such a manner that the faces of the slabs are approximately at equal distances from, and parallel with, the surface of the cylindrical mandril, both at its sides and underneath it, leaving the upper side open for the burnisher to travel over. The mandril is fitted with a properly insulated spindle, running in insulated bearings, and driven by suitable wheel gearing, &c. The whole of this arrangement is immersed, as before stated, in a bath of sulphate of copper. The mandril forms what is termed the cathode, and the copper bars the anode, of the *electric circuit*. The cathode is connected with the negative pole of an ordinary dynamo machine, and the anode with the positive pole. When the dynamo is set in motion, an electric current passes through the solution, and the following chemical changes take place. The sulphate of copper is decomposed, and the sulphuric acid is transmitted to the anode, there to attack and dissolve or combine with a quantity of copper equal to that which has been liberated or deposited upon the cathode.

The electric terms used in this matter of the deposition of copper are like those for electroplating and electrotyping, and it may be as well to describe them here.

1st. The terms "cathode" and "anode" are synonymous with the positive and negative poles of an electric or galvanic battery.

Then to measure the volume of electricity passed between these points the term "amperes" is used as the unit, like feet or cubic feet, for measuring in the usual mechanical sense.

2nd. Then for expressing the force with which the volume of electricity is propelled the term "volt" is used as the unit.

3rd. The resistance opposed to the electricity is measured by "ohms."

4th. The work done in the electrical circuit is expressed by "watts," in the same way that in a steam engine the power developed is expressed by H.P. To put this shortly—

1 ampere × 1 volt = 1 watt
1 watt × 746 = 1 E.H.P.

* The photographs in question were exhibited at the meeting.

These are the electrical terms employed by common consent in all European languages in connection with this science, and there are certain facts in relation thereto that are quite accepted.

The principal one to be noted here is that one ampere of electrical current will deposit ·005084 grains of copper per second per square foot of surface in a suitable bath and under fair circumstances. At the time I had the pleasure of witnessing the tubes being manufactured, the amperes and volts were measured by Siemens' standard instruments, from which, on the above basis, the quantity of copper electrically deposited in a given number of hours could be estimated.

In this way it was easy enough to judge of the H.P. transmitted through the dynamo to deposit a given quantity of copper or a given thickness of copper pipe of a given diameter. As to quality, it was by the nature of the process almost bound to be uniform; but in this respect the photos of the magnified pieces of copper, both before and after the burnisher has been applied, and the mechanical tests I have made, are the best proofs. I may describe the latter as follows :—

Two of the four pipes I witnessed being manufactured I brought to London. One of these pipes I had fitted with strong flanges properly secured in an apparatus especially made for the purpose, and tested to destruction. The other pipe I had cut into two pieces, and one of these pieces, marked A, is on the table for inspection. The other piece was cut and flattened out into a sheet, from which six test pieces were cut and prepared for making tensile tests. I also obtained from Messrs. J. Wilkes & Sons, of Birmingham, two solid drawn copper pipes of similar dimensions, and had them cut and tested in a like manner. The piece marked B is cut from one of these pipes.

In addition to these pipes I obtained from Messrs. Clelland & Thornburn, the well-known copper-smiths, of Glasgow, a brazed pipe of the same dimensions, made especially for my experiments, which was also tested to destruction, together with a sheet of best rolled copper, so that corresponding test pieces could be made to those made from the electro-deposited pipe, and the solid drawn pipe.

The results of these mechanical experiments are most interesting.

Pipe A, electro-deposited, stood a pressure of 3,450 lbs. per sq. in. before it burst. The material stretched and the pipe expanded uniformly until the copper was reduced in thickness from $\frac{3}{16}$ of an inch to $\frac{1}{16}$.

Pipe B, solid drawn, stood a pressure of 2,200 lbs. per sq. in. It also expanded, but not with the same uniform character as pipe A.

Pipe C, brazed from sheet copper, also stood a pressure of 2,200 lbs. per sq. in., and burst, as all brazed pipes do, near the line of brazing.

The tensile strength and ductility of the copper cut from pipe A is given in the following table :—

TABLE A.

DEPOSITED COPPER.

Marks on Specimen.	Dimensions in inches.			Tensile strain in tons.		Elongation per cent.		Contraction of Area per cent.	Remarks.
	Breadth.	Thickness.	Area.	Total.	Per sq. in.	In 8 in.	In 5 in.		
A 1	2·0	·175	·351	8·36	23·80	13·7	20·0	73	Electro-deposited copper cut circumferentially from the pipe.
A 2	2·0	·18	·36	8·36	23·22	13·0	17·5	68½	
A 5	1·0	·18	·18	4·32	24·00	12·9	16·0	82	Cut longitudinally with the pipe.
A 6	1·0	·18	·18	4·27	23·70	13·2	13·2	71	

The tensile strength and ductility of the copper cut from pipe B is given in the following table :—

TABLE B.

SOLID DRAWN COPPER.

Marks on Specimen.	Dimensions in inches.			Tensile strain in tons.		Elongation per cent.		Contraction of Area per cent.	Remarks.
	Breadth.	Thickness.	Area.	Total.	Per sq. in.	In 8 in.	In 5 in.		
B 1	2·0	·195	·39	8·0	20·5	3·75	7·1	12·8	Solid drawn copper cut circumferentially from the pipe.
B 2	2·0	·195	·39	8·0	20·5	3·75	6·9	12·8	
B 5	1·0	·190	·19	3·8	20·0	2·90	7·0	43·6	Cut longitudinally from the pipe.
B 6	1·0	·190	·19	3·8	20·0	3·10	7·0	36·8	

The tensile strength and ductility of copper cut from sheet copper, such as would be supplied for making pipe C, is given in the following table :—

TABLE C.

ROLLED SHEET COPPER.

Marks on Specimen.	Dimensions in inches.			Tensile strain in tons.		Elongation per cent.		Contraction of Area per cent.	Remarks.
	Breadth.	Thickness.	Area.	Tota	Per sq. in.	In 8 in.	In 5 in.		
C 1	2·0	·265	·53	7·46	14·0	45·0	30·0	44·5	Rolled sheet copper cut in the direction in which it was rolled.
C 2	2·0	·265	·53	7·46	14·0	44·0	30·0	45·5	
C 5	1·0	·265	·265	3·72	14·0	45·0	35·5	31·0	Cut across the direction in which it was rolled.
C 6	1·0	·265	·265	3·71	14·0	42·0	33·5	31·5	

It will be seen from these tables that the tenacity in the normal state of these three descriptions of copper—the electro-deposited, the solid drawn, and the rolled sheet—are $23\frac{3}{4}$, $20\frac{1}{4}$, and 14 tons per square inch respectively.

The very superior ductility of the pure electro-deposited copper is clearly shown by the manner of breaking, the elongation being chiefly confined to the neighbourhood of the fracture; and whereas the contraction of area at the fracture in the solid drawn copper is 12·8 per cent., and in the sheet copper 45 per cent., in the deposited copper it averages 72 per cent.

The tenacities shown by the test pieces are confirmed by the pressures at which the electro-deposited and solid drawn pipes burst under hydraulic pressure, and, as before stated, the uniformity of the deposited material is very conspicuous.

In order to ascertain how deposited copper behaves as compared with solid drawn and ordinary sheet copper, and how its strength and ductile properties are affected by the action of heat, such as is contained in steam pressures that are now common, I have had a series of experiments made, the results of which are given below.

TABLE D.

Table Showing Effect of Temperature in Different Descriptions of Copper.

Mark on Specimen.	Thickness.	Breadth.	Area.	Total Load in tons.	Tons per square inch.	Percentage of Loss.	Temperature.	Remarks.
P 1	·237	2·0	·474	6·80	14·33	...	60°	Cold.
P 2	·237	2·0	·474	5·05	10·66	26%	390° F.	Rolled sheet copper.
P 3	·237	2·0	·474	5·00	10·55	26%	390° F.	
S 1	·192	2·0	·384	7·70	20·0	...	60°	Cold.
S 2	·195	2·0	·390	5·55	14·23	25·2	390°	Solid drawn copper.
S 3	·194	2·0	·388	6·10	15·7	...	390°	
T 1	·179	2·0	·358	5·50	15·35	...	390°	
T 2	·179	2·0	·358	5·25	14·65	...	390°	Electro-deposited copper.
T 3	·179	2·0	·358	5·45	15·2	...	390°	

The specimens were immersed in an oil bath while they were in the testing machine, the temperature of the oil being maintained by a gas flame; and by this

means the specimens were pulled asunder at the temperatures given, which correspond with the temperature of steam at 200 lbs. pressure.

The results of these experiments are embodied in the preceding table, and are very interesting. The electro-deposited copper, it will be seen, as well as the solid drawn copper, stood about 15 tons per square inch, while cold rolled sheet copper broke at about 10½ tons, at the temperature of 390° Fahrenheit.

Comparing these tests with the interesting series made by Dr. Kirk at Lancefield, to which I have before referred, and published in *Engineering* in December, 1887, I find there were 23 specimens of copper plates tested at the same temperature, viz., 390°. Some of these were cut across brazed joints, and others clear of the brazing.

Of the nine samples which had been cut across the brazed joint, the mean tensile strength per square inch was 10·53 tons ; but they varied in strength from 8·59 tons up to 12·32, or about 40 per cent.—say, 20 per cent. above, and 20 per cent. below the average.

The fourteen samples that were cut clear of the brazing broke with a mean tensile strength of 11·81 tons per square inch, the variation ranging from 10·19 tons to 13 tons per square inch, or from about 10 per cent. above to 10 per cent. below the average.

Similarly comparing with the experiments made by me at the time of the *Elbe* explosion, the mean of four samples of sheet copper, at temperatures varying from 300° to 370° Fahrenheit, was 9·93 tons.

Other experiments also go to show that ordinary sheet copper cannot be accorded a breaking strain of more than about 10 tons per sq. in. at the temperatures of high pressure steam, apart from the danger and uncertainty arising from brazing which was so disastrously exemplified in the case of the *Elbe*, and also the S.S. *Lahn*. In the case of the electro-deposited copper, as also in solid drawn copper pipes, these experiments indicate a breaking strain at these temperatures of about 15 tons per sq. in., or an increase of 50 per cent., and an absolute freedom from the dangers of brazing. This is a step in advance for which I am sure Marine Engineers will be grateful, and it comes none too soon, for our increasing high pressures have here discovered a weakness and danger that was bound to cause anxiety.

I find solid drawn pipes are now being made of larger diameter than hitherto, and I am not aware what the limit of their process of manufacture can go to : at any rate, there is no limit to which the diameters of the electro-deposited pipes can be made. Many other advantages are claimed for these electro-deposited pipes, which I have not investigated, but so far as steam pipes are concerned, it is obvious that absolute

uniformity of density, thickness, and tensile strength, and true circular section (all of which are important qualities), can be obtained.

It is also established that copper deposited under a burnisher can be varied in tensile strength from the ordinary granular form to a material having high tenacity, and as it obviates the necessity for the steam pipes being put into the fire for brazing purposes, the strength and safety at high steam temperatures may be still further increased, and if so, we shall, I am sure, be further gratified.

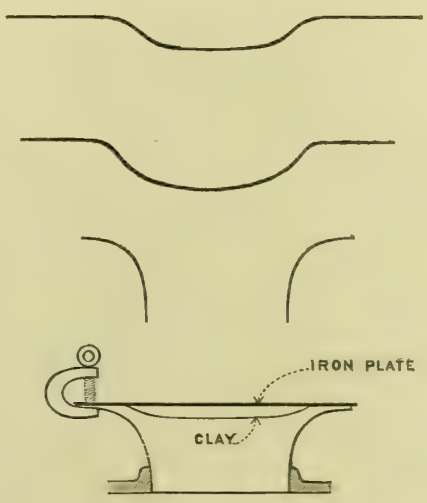
I cannot conclude this paper, which I hope may not be without interest to the members of this Institution, and to others engaged in the manufacture and use of copper pipes, without expressing my thanks to Messrs. Maudslay, Sons & Field, for the great assistance they have been to me in carrying out a number of experiments, notably the bursting of the pipes, for which special appliances had to be devised, as also for the experiments at high temperatures ; my thanks are also due to the Leeds Forge Company, who placed their testing machines at my disposal, and others who supplied me with copper and the necessary assistance and appliances for conducting these investigations.

DISCUSSION.

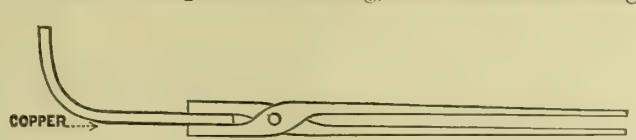
Dr. A. C. Kirk, LL.D. (Member of Council) : My Lord, although my name has been mentioned in the paper, it would be quite out of place for me to make any prolonged remarks. I will only say one or two words with reference to the brazed copper pipes that we have been for ages in the habit of using. Do not let us forget that they have been very good servants hitherto in times past, and are not to be altogether thrown away. The experiments that Mr. Sinclair made, and which are given in detail in a paper which was read before the Institution of Engineers and Shipbuilders here, show that the ordinary brazed copper pipe made by a good tradesman is a very satisfactory and reliable thing indeed. Further, seeing that out of the large number of high-pressure engines which have been made with brazed steam-pipes we have had only two notorious cases of steam-pipe explosion, I think we must admit that their usefulness is not by any means exhausted, and the only thing you can say against them is that their goodness depends much on the skill of the tradesman who does the brazing. You may find within a length of 12-inch pipe a difference in strength, as Mr. Parker puts it, of perhaps as much as 30 per cent. This has long been known, and a very large margin of strength has been habitually in use. But still with all that, as I say, it is a very good servant. We know that the thickness and the strength of copper pipes in use have not been arrived at by abstract calculation, but have been the result of very long experience, and in that way our present factors of safety for copper pipes cover all the irregularities that are likely to occur when a good tradesman does the work, although the copper is soft ; and all I have got to say is that when we substitute unbrazed pipes, whether solid drawn or whether electro-deposited pipes, we ought to make a reduction in thickness, while at the same time we will eliminate many risks from bad workmanship. From the experiments which Mr. Sinclair made, I should put the proper reduction in thickness roundly at 25 per cent. when the unbrazed pipe replaces the brazed one. I do not propose getting rid of brazing altogether. We have questions of flanges to deal with, and when we come to large pipes we have the

question of bending to take account of. The bent pipe may be less trustworthy than the brazed. I am not aware that there is any information in this world about the bending of a 12-inch copper pipe, and as to how much it is worth after it is bent, or even how the bending is to be done. In that case I presume we should have to have recourse to brazed copper or brass castings for bends, and content ourselves with straight pipes when solid. It is quite evident that such things as 12-inch solid drawn pipes can only be applied to a very limited degree. Where the ship is made to give way a little to the machinery, main steam-pipes may be made straight, with brazed or cast bends; but there are many pipes of large size connecting parts of the engines that cannot be made so—they must be made bent, and in that case they must still be built and brazed. However, the advance which is making in solid drawn pipes, and no doubt also in the pipes which Mr. Parker has described, will be a very useful advance indeed; but we are not to suppose, as far as we have gone at present, that they will certainly replace brazed pipes.

Mr. F. C. Marshall (Member of Council): My Lord President and gentlemen, I do not wish to occupy the time of the meeting further than to confirm to some extent the results described by Mr. Parker in his very able paper. I have had sent from Newcastle a piece of an expansion joint, showing precisely the effect that Mr. Parker has described round a considerable portion of its circumference, though not entirely. In order to put the matter precisely, my Lord, I have requested Mr. Milton, a member of our Council, to give me the history of the pipe upon which he has experimented, and with your permission I will read the letter he has sent:—"I have sent by passenger train the piece of the copper expansion joint, and also the test pieces cut from it. The history of the piece is as follows: It was delivered here as a circle, and was hollowed cold by a mallet. Then it was heated to a blood-red colour, and dished hot with a mallet. A small circle was then cut out of it, and the inner edge drawn square, still being worked at blood-coloured heat. The flange was then put on it, and it was brazed over a flat fire, the upper part having an iron plate cramped on it to keep the heat down, and to stiffen the copper piece to hold it by, the iron plate being clayed over on inside. The flange was successfully brazed on, and on cleaning the piece afterwards the minute cracks were observed for about five-sixths of the circumference. After cutting the flange off, it has been bent about to observe the effect of the cracks"—which are very perceptible, and are distinctly described by Mr. Parker. They show that the effect of the heating has been to crack the body of the copper nearly half through, leaving a distinct black crystalline mark where it was opened out. "This history has been got from the foreman. The workman who did the work is one of his most skilful men.



I have had two pieces cut off the expansion joint at the part where there were no cracks, and have had them treated over a fire. The first one, you will see, was on the point of melting, the under side being fused and just ready to drop. On the upper side a piece of spelter (solder) was melted long before the temperature was too much raised. This piece had the overhanging weight of itself when on the point of fusing, but no cracks were developed, and it has been flattened out since without any defects showing them-



selves. The other piece was, unfortunately, heated just too much, and a piece dropped off it, not being able to bear its own weight. This second piece has developed the small cracks, similar to those in the original expansion joint piece. From the flat portion near the defects, I have had two test pieces cut and tested. One was well hammered, marked H. The other annealed, marked A. The test results show them to be very good. Annealed, 13·9 tons per square inch, with 45 per cent. elongation in 4 inches. Hammered, 14·95 tons, with 29 per cent. elongation. I think the heating experiment shows that these defects are only produced at a temperature varying very little from fusing point, and that the margin of temperature at which the copper is brittle is so small that it is very improbable that it can be reached, except very locally, without some part showing by the blistered appearance that the copper has been overheated." This fully confirms Mr. Parker's view that at certain points—and it is also confirmed by Dr. Kirk—at certain temperatures copper does become disintegrated, and produces this effect. I quite confirm Dr. Kirk's view with reference to the brazed pipes. I should be sorry to give up brazed pipes after such long service. It is to be observed in the case of the *Elbe*, if I remember rightly, the bursting was not at the soldered joint, but immediately adjoining it, showing that the copper heated.

Dr. A. C. Kirk: I think that is always the case. It is adjoining the joint where the copper is weakest.

Mr. F. C. Marshall: If the temperature is kept down and the workmanship is properly carried out, the brazed pipe is an excellent servant, as Dr. Kirk has said. It is further to be observed that in the *Elbe* pipe the explosion took place near the brazing of the flange; it therefore requires that we should give greater attention to that part of our work; and while it would not be well to dispense altogether with the brazing of flanges, and instead of that to substitute the old procedure again of riveting them together, and depending solely on the riveting, I think that it is a question well worth our consideration, and it might be a useful outcome to Mr. Parker's paper. I am sure that we are very much indebted to Mr. Parker for having brought this matter before us. It will induce greater caution on the part of marine engineers with regard to a matter which perhaps has not up to the time of our using very high pressures of steam received the proper amount of attention.

Mr. G. B. Rennie (Member): My Lord, you will perhaps allow me to say a few words on this subject. I think, first of all, we must all feel very much indebted to Mr. Parker for having brought this subject before us. The question of copper pipes and copper working has really so slowly advanced as compared with almost every other part of marine engineering, that I think we ought to hail with great satisfaction any new process of making copper pipes, especially the more difficult parts of copper pipes, in the way of bends and joints. Really if one looks back one sees very little improvement in copper pipes since the time of Alexander the coppersmith. With the exception of solid drawn pipes, and greater care being taken in their manufacture; we are still subject to the hand-made pipe, and to the skill of the individual workman. Of course if such a result can always be obtained as Mr. Parker has shown in his experiments with a strength of 24 tons (Table A), compared with 14 tons (Table C), it is an immense improvement in every way. There is only one thing that struck me in the description of the tests of these pipes, and that is with regard to the pipe marked A, which is the deposited pipe. I see the material of the pipe does not seem to be quite so uniform as one would expect. Nearly the whole effect of the bursting power seems to be at one end. This must be either due to the fact that the metal was not equally deposited, so that that part is thinner than the lower part, or possibly the metal has not been quite uniform. In the case of C and B pipes the extension due to the bursting

pressure seems to be pretty well equal all along the whole cylinder, the rupture being towards the centre. I should be very glad if Mr. Parker would give us an explanation of this, which does not seem to quite carry out what he said. We must all agree with what Mr. Kirk and Mr. Marshall say. We have all grown up and found the present means of making copper pipes most valuable, and the skill of the men making them has been brought to a very high state of perfection, but still anything that will make an improvement in the process of manufacture of copper pipes I think all engineers must be very grateful for.

Admiral Sir John Hay, K.C.B., D.C.L., F.R.S. (Vice-President) : I have to ask a question of Mr. Parker, my Lord, which I think is not irrelevant to the paper, with reference to the copper which is deposited on the mandril, and which is changed into a fibrous condition by the agate burnisher. I should like to know whether, when the copper pipe so produced and made fibrous, is submitted to vibration, or to the repeated blows of the expansion and contraction under high steam or great heat, the fibrous nature of the copper may not be supposed to be altered into a granular condition—a condition in which it is less tenacious and less able to resist pressure than copper produced and rolled under the ordinary conditions. None of the accomplished engineers who have spoken have asked that question, and perhaps it is irrelevant ; but at the same time, it might be satisfactory to some minds to know whether copper pipes produced by electro-deposition are not liable under conditions of varying strains to be altered from a fibrous to a granular condition, in which they no longer have the tenacity which appears to appertain to them under their first condition.

Mr. Wigham Richardson (Member) : My Lord, I would ask Mr. Parker if he can give us any information with regard to the *analysis* of the copper. I presume, as deposited copper, it must have been absolutely pure copper. The other copper experimented upon, which he obtained from the pipe-makers, would, I suppose, be commercial copper, containing a certain amount of arsenic in it. Mr. Parker speaks in this paper at p. 56, of the superior ductility of the electro-deposited copper. Perhaps he will kindly tell the meeting what is the behaviour of the copper when being brazed and hammered out. I know nothing about copper except what I have been told, but the reason I ask the question is that I have been told by a gentleman who has had large experience, that copper with a certain amount of arsenic in it is more suitable for the purposes copper is usually put to in Birmingham, of being hammered out into utensils of domestic economy, such as kettles and pans. In other words, that copper with some amount of arsenic in it is more easily treated than copper which is called in the trade conductivity copper ; that is to say, copper so pure that it is reserved for electrical purposes. Any information that Mr. Parker could give us on that point would add, I think, to the completeness of his paper.

Mr. Clark (Visitor) : My Lord and gentlemen, I feel very considerable diffidence in rising to address you ; but perhaps, as I have been engaged all my life, although perhaps a comparatively short life, at least all my business life, in connection with the manufacture of copper pipes, both brazed, seamless, and electro-deposited, that may be some little excuse for my venturing to offer a few observations at this meeting. I was struck in the first instance with the remark which I saw in the paper, that large seamless copper pipes were only now being introduced. I may say that for the last fifteen years, at any rate, the firm with which I am connected have been making seamless drawn copper pipes up to 10 in. in diameter. I remember when first I went to my place of business, fifteen years ago, seeing those turned out, and within recent years we have increased the diameter very considerably

If this is not known to the engineering world, I can only ascribe it to our undue modesty; and, as far as I am concerned, I will endeavour to remedy that defect. We have in the Exhibition at the present time a large exhibit of entirely seamless pipes of both brass and copper; among the rest some 24 ft. long and 10 in. bore, and we would have made them 30 ft., but the roof of the Exhibition buildings would not allow of their being put up. We have besides some cylinders of 15 and 18 in. diameter of solid drawn copper; so that it seems to me, as far as the sizes of main steam-pipes are concerned we have gone far in the direction of meeting the demand for large pipes. If a further demand arises we can meet it. There is no limit, or practically none, to the size which seamless drawn copper pipes can be made. The only novelty that has struck me in connection with the manufacture of electro-deposited copper pipes by Mr. Elmore is the use of the agate rubber. We have a large and costly plant in connection with the deposit of copper in iron cylinders and for various other purposes, and we have made tubes experimentally in the same way, but they have not proved either so good or so cheap as tubes made by the system now in use, although the copper gives a remarkably close grain fracture, and is excessively tough. At the same time the point which I particularly draw your attention to is this, that at the temperature of 390 degrees, which I understand is the working temperature of these main steam-pipes, the electro-deposited copper gives no better result, in fact a shade worse result, than seamless drawn copper. You will find this demonstrated in the paper in Table D; moreover, as the diminution in strength between the normal temperature and 390 degrees in the case of the electro-deposited copper is so very great, it would seem logically to follow that if you got anything higher than 390 degrees it would decrease in the same ratio, and would thus become much worse than a seamless drawn copper pipe. It must also not be lost sight of by the engineers that if copper is offered as being such as will stand an unusual tensile strain, the condition of the copper must at the same time be taken into consideration (*i.e.*, is the metal hard or soft ?). By mechanical work put upon copper, such as rolling, drawing, hammering, &c., in the cold state, its tensile strength can be increased materially, but this is at the expense of its ductility. If samples of various descriptions of copper be carefully "annealed" before testing, it will be found that electro-deposited copper will bear the least tensile strain of any. The process of the agate rubber is one which, like rolling or hammering, merely puts mechanical work upon the copper. I do not know that I have anything further to bring before you, except to repeat that our experience of the manufacture of these electro-deposited pipes is that they are much more costly to make than are those of solid copper; and the time required to make these pipes, of which we have a sample here, was, as you will see by the paper, 170 hours. Therefore it seems to me that a strong element in considering this question is the great length of time required to manufacture these pipes compared with the solid drawn and brazed pipes, which can be made at a day or two's notice. I may say in conclusion that we have given considerable attention and time to this question of making tubes by electro-deposition, but have come to the conclusion that it is not so satisfactory a method as that of making them by the seamless drawn process.

Mr. W. Parker (Member of Council): My Lord, when writing and reading this paper, I did not think there would be any discussion upon it. My object was to give to the members of this Institution the results of the investigations I had made into the causes of the explosions that occurred on board the steamers *Elbe* and *Lahn*, and also to give to the meeting the experience I have gained while investigating the manufacture of electro-deposited copper, and comparing its properties with the properties of solid drawn and plate copper, with a view to having pipes in future made without a brazed joint, and thus to try to eliminate the element of danger which, to my mind, was undoubtedly the cause of

these unfortunate accidents. I am glad to find, from Mr. Marshall's remarks, that he has taken hold of the point I refer to. It is simply this: when a copper pipe is being brazed, it is raised to a temperature at which spelter melts, and, comparatively speaking, at a few degrees above this temperature copper becomes absolutely rotten, and will break even with its own weight. It then depends upon the skill of the workman who brazes the pipe whether you have a sound pipe or a pipe having a latent defect in it. If you look at the fractures of these pieces of copper, which fractures have been produced artificially, it will be seen, by the discoloured portions, that the copper had cracked almost through the plate while it was at this temperature, and had been holding only by the small portion having a bright appearance. These fractures of specimens of copper correspond exactly with the fractures that appeared, not only in the *Elbe's* pipe, but also in the other pipes, which, while being tested, gave way at such alarmingly low pressures. I think you will agree with me that there is very great risk attending the brazing of copper pipes—not at the brazing, but, as Dr. Kirk has put it, outside the brazing. This investigation has shown that latent cracks, such as shown by these specimens, did exist in the pipes that gave way, and that we are always more or less liable to such cracks if we continue to adopt the present practice. Mr. Marshall said, strange to say, these pipes generally gave way near the flange. I think that is easily explained. In brazing the seam of a pipe, it is done in short lengths, and only requires to be heated in short lengths; but when brazing a flange, the pipe is placed on end on the fire, and for a short length the pipe is heated all over. This part is made much softer than the other parts of the pipe, and it gives way there first. Mr. Rennie has asked a question about the uniform stretching of the copper in the deposited pipe, and I think he infers that it has not stretched as uniformly as the copper in the other pipes. This is entirely wrong. It will be noticed that the deposited pipe has certainly bulged and stretched to a much greater extent than either of the other two, and, if noticed, in a more uniform manner. As stated in the paper, the material was originally 3-16ths of an inch thick. As will be seen, the pipe has, in the locality of rupture, increased considerably in diameter; it has not shortened, but the material has been uniformly reduced to 1-16th of an inch in thickness; whereas the solid drawn pipe has not been reduced to more than $\frac{1}{8}$ of an inch, and that only in the neighbourhood of the rupture.

Mr. F. C. Marshall: Were all these specimens the same length to begin with?

Mr. W. Parker: No; this one was cut shorter. Sir John Hay wanted to know—and this is, I think, the most important point of the paper—how copper behaves under temperature. As a matter of fact, all copper that has work put upon it loses a great amount of its tenacity under increased temperatures. The harder you work it, or the more density you give to it, the greater the loss will be. The tenacity of the electro-deposited copper was, in its cold state, $24\frac{3}{4}$ tons per square inch; the solid drawn copper had a tenacity of 20 tons, and the plate copper a tenacity of about 14 tons. When subjected to high temperatures these high tenacities vanish very quickly; at a temperature of 390° F., equal to the temperature of steam at a pressure of 200 lbs. per square inch, the electro-deposited copper falls to 15·3 tons, or a loss of 61 per cent.; the solid drawn to 14 tons, or 30 per cent.; and the plate copper to $10\frac{1}{2}$ tons, or 25 per cent. Mr. Wigham Richardson asked a question about brazing the pipes which I did not quite catch.

Mr. Wigham Richardson: About hammering them.

Mr. W. Parker: Here are specimens which have been hammered from the solid pipe into the shapes you see. This deposited copper is perfectly malleable and soft, having a stretch of over 40 per cent.

in a length of 8 inches, against only 3½ per cent. in the case of solid drawn copper, as will be seen by reference to the tables. I was not aware, until Mr. Clark told us, that solid drawn pipes can be made of such enormous lengths and of such large diameters. I am very glad to hear it, because anything that will eliminate the evil which, to my mind, exists in copper pipes as now made, will, I am sure, be very welcome. As I said before, I did not expect a discussion on this paper, but I am glad something has been said, and I venture to think that the results of the investigations, which I have taken some trouble to make, will tend to throw some light upon a subject which, we must all admit, is one of very great importance.

The PRESIDENT: Gentlemen, I am sure you will desire me to accord your unanimous thanks to Mr. Parker for the extremely clear and able paper he has given us. I may also congratulate you upon the discussion which has ensued upon it. It has not been a very long discussion, but I am sure you will agree with me that it has been a thoroughly practical and useful one. I may perhaps also thank Mr. Clark for his valuable contribution to the discussion.

ON THE COURSE OF INSTRUCTION IN NAVAL ARCHITECTURE AT GLASGOW UNIVERSITY.

By Professor P. Jenkins, Member.

[Read at the Thirtieth Session of the Institution of Naval Architects, July 25th, 1888; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

Eleven years ago, on the occasion of the previous visit of the Institution of Naval Architects to Glasgow, Mr. White read an interesting paper on the course of study pursued by students of Naval Architecture at the Royal Naval College. That paper was written, as Mr. White stated at the time, mainly to call attention to the failure of the School of Naval Architecture, and its successor the Royal Naval College, to attract students from the private trade, and in the hope that a better acquaintance with the character and scope of the course of professional training attained at the College might lead to an accession of qualified students.

At that time, and for some years after, the Naval College was the only institution existing in this country, at which it was possible for a student to receive adequate instruction in naval architecture; but in 1883, as the members are no doubt aware, the John Elder chair of Naval Architecture, including Marine Engineering, which owes its existence to the munificence of Mrs. Elder, was endowed; and as nearly five years have now elapsed since the classes in Naval Architecture were first formed, it has occurred to me that it would be most appropriate if, following Mr. White's example, I were to lay before this Institution, on the occasion of its second visit to Glasgow, a brief account of the progress of the classes at the University, and of the course of study pursued.

I felt the more disposed to undertake the preparation of this paper from the knowledge of the fact that from the time of the formation of the Institution down to the present day, its members have taken the warmest interest in the education of naval architects: indeed one of the first acts of the Council was to impress upon the Admiralty authorities of that day the necessity for the re-establishment of the School of Naval Architecture, twice previously abolished.

From the failure of the School of Naval Architecture, and its successor the Royal

Naval College, to attract students from the private trade in any number, it might perhaps have been inferred that the classes at the University would receive very little support. As a matter of fact, however, the manifest want of such instruction, coupled with the high reputation of my predecessor Dr. Elgar, sufficed to attract to the University from the beginning a tolerably large number of students; and, although it is hoped that a further increase will take place in subsequent years, I think that the attendance up to the present time cannot, in view of some adverse circumstances, not the least of which is the prolonged depression which has hung over the shipbuilding industry, be considered as other than satisfactory.

During the first year nineteen students attended the day classes; in the second year the number was seventeen; in the third year seventeen; and in the last session twenty-one. Although a large proportion of these students belong to Glasgow and its immediate vicinity, no less than 46 per cent. come from other towns of the United Kingdom, and from other countries. Students have been drawn from Greenock, Dundee, Newcastle, Sunderland, Middlesbro', Cowes, Plymouth, and Preston, in the United Kingdom, and from the United States, Belgium, Russia, and Japan.

The session in the Faculty of Arts, to which Naval Architecture is at present attached in this University, opens at the beginning of November, and closes towards the end of April. The session thus occupies nearly six months. The full course extends over three sessions, but students who are found to be sufficiently qualified are not required to take the first year's course, a point of some importance to those who are able to spend only a limited time at the University. Unlike the Royal Naval College, we have no qualifying entrance examination except for those students who propose to take the degree of Bachelor of Science on the side of Naval Architecture.

Instruction in Naval Architecture is given on two mornings of each week, in the form of a lecture of one hour's duration, and in the afternoons of the same days two hours are devoted to practical instruction in ship drawing, ship calculations, and ship design. It may be added that as the course in Naval Architecture has now assumed a tolerably permanent form, it is proposed to add a day each week to the first year's course in the coming session for instruction in the Theory of the Steam Engine, and in subsequent sessions to similarly augment the scope of the teaching in the second and third years' courses. It is also proposed to engage the services of an assistant next session for the teaching of engine drawing and marine engine design to those students who wish to make a special study of marine engineering. These classes will probably be held in the evening.

In the interest of those who are unable to attend the classes at the University on account of their employment in the shipyards during the day, my predecessor, Dr. Elgar, arranged to give a course of evening lectures, twelve in number, each session,

and the practice has been continued by myself. The subjects selected for these lectures have been, "The Stability of Ships," "The Resistance of Ships," and "The Strength of Ships." In all, sixty-six students attended the first evening course, forty the second, and forty-two the third.

Some of the difficulties experienced by Mr. White eleven years ago in connection with the teaching of private students at the Royal Naval College are similarly felt at the University. Students who have not previously spent some little time in a shipyard cannot expect to receive as much benefit from the course as those who have become familiar with the details of ship construction; and I should be glad to see future students better prepared as a body in this respect. At the same time, it cannot be denied that the objections which stand in the way of the completion of his apprenticeship by a student before attending the University are so great as to make the general adoption of this plan highly improbable. Another course, not unknown in Scotland, viz., that of spending the summer months in the shipyard, and the winter months at the University, has been adopted by some of the students with very satisfactory results; and although this plan is viewed with disfavour, I believe, by some employers, it is to be hoped that its obvious advantages in causing students to more intelligently appreciate that which is going on around them in the shipyard, may be held to more than counterbalance the objections raised against discontinuity of service.

Again, as I have already stated, we have no compulsory entrance examination for students who do not propose to go forward for the degree; and I very much fear that some of the students who matriculate would not be able to pass satisfactorily the entrance examination at the Royal Naval College. I do not, however, regard the absence of an entrance examination, in cases where no degree is looked for, in view of all the circumstances of the case, as an unmixed evil. Many, if not most, of the draughtsmen who do the work of our shipyards, and do it well, would probably fail to pass satisfactorily an entrance examination such as that prescribed at the Royal Naval College, or at the University when a degree is contemplated; and the question which has to be considered is whether students who present themselves shall be made acquainted, so far as possible, with the principles on which the rules they employ in the drawing office are founded, or whether, as the scope of their mathematical knowledge is not large, they shall be denied the means of acquiring even such information as requires no greater mathematical knowledge than they possess. The first year's course, for instance, can be mastered by students possessing only an elementary knowledge of algebra and hydrostatics, and towards the end of the session of very elementary trigonometry and mechanics, and the industrious student who is no further advanced has opportunities within the walls of the University of increasing the extent of his mathematical knowledge, and of preparing himself each session for the succeeding year's course.

Proceeding to the consideration of the actual course of instruction, I may observe that the subjects taught may be classified under the following heads: Ship Calculations, Laying Off, Stability of Ships, Strength of Ships, Waves, Resistance of Ships, and Ship Design. The Rolling of Ships has not yet formed part of the regular curriculum, because the students as a body have not possessed sufficient mathematical knowledge, but I hope to take up this branch of the subject next session with a limited number of advanced students. During the first session the lectures embrace Laying Off and Ship Calculations. Under the latter head are included:—

The several rules for the determination of plane areas, with proofs.

Methods of combining the several rules.

Determination of area of a plane figure formed by two radii and a curved boundary.

Geometrical method of finding the area of a plane figure.

Application of the rules in determining the volume of a vessel below any given water plane.

Elementary principles of Hydrostatics regarding the properties of floating bodies.

Curves of Displacement, Tons per Inch Immersion, and Area of Midship Section.

Change of Draught in passing from salt to fresh, or partly salt water, and *vice versâ*.

Properties of the Centre of Gravity.

The Centre of Buoyancy—Determination of its position vertically in a vessel corresponding with any water plane, with proof of the accuracy of the method employed.

Change in height of the Centre of Buoyancy with change in draught, and method of drawing the locus adopted in practice.

Longitudinal position of the Centre of Buoyancy.

Centres of Gravity of plane areas of various forms, both transversely and longitudinally.

Transverse Metacentre. The several kinds of equilibrium. Change in height of Transverse Metacentre in a vessel with change of draught, and method of drawing the locus adopted in practice.

Metacentric Diagram.

Longitudinal Metacentre. Uses to which the Longitudinal Metacentre is commonly put.

Change of trim produced by shifting a weight longitudinally in a vessel.

Moment to change trim one inch.

Effect upon the trim of placing a known weight on board a vessel in any position.

Centre of Gravity of a plane area by polar co-ordinates, and moment about one of the radii.
Centre of Effort—Determination of its position both longitudinally and vertically.
Estimate of position of Centre of Gravity of a vessel from known data regarding a similar vessel.
Volume and Centre of Gravity of cargo space.
Centre of Gravity of a vessel filled with homogeneous cargo.
The Centre of Pressure.
The Tonnage Laws.
The Freeboard of Ships.
Kirk's Analysis.
Methods of determining the surface of a vessel.
The Inclining Experiment.
Correction of results in respect of weights which require to go on board, or to come out, or to be shifted.
Curve of Stability, and its chief features.
Metacentric height as a measure of initial stability.
Construction of Curve of Stability for some bodies of simple form.
Equilibrium of homogeneous prism of rectangular section.

In the afternoons the students lay off the fore or after body of an iron sailing vessel. They are furnished also with the drawings of a vessel, and each student is required to work out the displacement up to each of the several water planes, and to construct the curve of displacement and curve of tons per inch immersion. The heights of the Centres of Buoyancy and of the Transverse Metacentres corresponding with the several water planes are determined, and the metacentric diagram completed. In addition, the longitudinal position of the Centre of Buoyancy is calculated, and the height of the Longitudinal Metacentre corresponding with the load draught, as well as the moment to change trim one inch.

The second session commences with the elementary parts of the Strength of Ships, and afterwards the Stability of Ships is taken up at the point to which it had advanced at the close of the previous session, and is fully discussed. The lectures embrace the following :—

Determination both mathematically and graphically of the Stresses on parts of combinations subject to simple Tension or Compression.
Simple Shearing.
Simple Bending.
Curves of Shearing Force and Bending Moment for Beams variously loaded.
Properties of Curves of Shearing Force and Bending Moment.

Curves of Shearing Force and Bending Moment for bodies of uniform section floating in still water and variously loaded.

Curves of Buoyancy, Loads, Shearing Force, and Bending Moment for an actual vessel floating in still water with an assumed distribution of weight.

Properties of Iron and Steel.

Stress and Strain.

Effect of Discontinuity of Material on Stress.

Effect of Punching and Drilling on the Tenacity of Plates.

Bearing Pressure.

Hooke's Law. Modulus of Elasticity—Permanent Set.

Shearing and Tensile Strength of Steel Rivets.

Riveted Joint of Maximum Efficiency.

Relation between Pitch, Diameter, and Thickness in single and double riveted Joints of maximum efficiency.

Hydraulic compared with Hand Riveting.

Diagrams of Stress and Strain for test pieces of Iron and Steel.

Slip of riveted Joints.

Estimate of Breaking Strength of Butt Joints in ship construction.

Moment of Inertia of a plane surface and of a solid body.

Proof of formulæ for height of Transverse and Longitudinal Metacentres above Centre of Buoyancy.

Expression for stability of Prism of rectangular section up to inclination at which an edge is immersed or emerged.

Attwood's Formula.

Preparation of body plan from drawings for Calculation of Statical Stability.

Calculation of righting Arm by the ordinary method at the several Inclinations.

Correction for the Layer.

Check calculation of Stability at 90° inclination.

Independent method of calculating Stability at any inclination.

Inclusion of enclosed erections upon deck in the calculation of Stability.

Most critical conditions as regards Stability in which a Merchant vessel can be placed.

Effect of Coal Consumption on the Stability.

Having given the Curve of Stability corresponding with one Displacement, to deduce that at another.

Effect upon the Initial Stability of adding a small Weight.

Correction of Data supplied by Inclining Experiment, when necessary, on account of free water between the floors.

Polar Diagram of Stability.

Moseley's Formula for Dynamical Stability.
Deduction of curve of Dynamical Stability from curve of Statical Stability.
Independent calculation of Dynamical Stability.
Cross Curves of Stability, with the several methods of calculating the same.
Effect upon the Stability of free water in the hold, with or without cargo in the compartment.
Effect upon the Stability of Cellular Bottom or McIntyre Tank, both intact and broached.
Effect upon the Stability of bilging a compartment of the hold, both when it is empty and when it contains cargo.
Stability of a Petroleum Steamer while loading or discharging, and when laden.
Mechanical methods of determining the Stability of a vessel.
Principles on which the Roller and Spindle and Pivot Planimeters are constructed.

In the afternoons the students of the second year determine graphically the stresses upon certain simple combinations, such, for instance, as in the case of a derrick to a mast supporting a heavy weight, and then proceed to construct curves of Shearing Force and Bending Moment for uniform bodies floating in still water and loaded in various ways. Curves of Buoyancy, Loads, Shearing Force and Bending Moment are also drawn for an actual vessel floating in still water under an assumed distribution of weight. The drawings of a vessel are next taken, the body plan prepared, and a curve of stability corresponding with a fixed displacement worked out. Upon the same vessel an enclosed bridge-house is next placed, and the necessary correction in the work introduced to include the effect upon the stability. The students then construct a polar diagram of stability, and draw in the Metacentric Curve or locus of pro-metacentres for transverse inclinations, and the locus of the centre of buoyancy and the curve of flotation. Finally, with the body plan as previously prepared, the data for cross-curves of stability at inclinations of 30°, 60°, and 90° are determined, and the curves drawn.

The lectures of the third session are taken up with the strength of ships, a few problems on the Stability of Ships, the Geometry of Ships, Trochoidal and other Waves, the Resistance of Ships, and Ship Design. They embrace the following :—

Stability of vessel partially waterborne.
Stability of vessel with masts and sails.
Principle enunciated by Dr. Elgar.
The Shifting of Cargoes.
The action of the Rudder.
Mr. Crossland's Proposition.

Effect of free water contained in a compartment on one side of a middle-line bulkhead upon Initial Stability.

The Principle of the Integrator.

The Surface of Buoyancy.

Locus of Metacentre; circumstances under which cusps occur.

Positions of equilibrium, both stable and unstable.

Absolute Stability, Relative Stability, and Absolute Instability.

The surface of Flotation.

The Indicatrix. Initial Stability of a vessel turned about a horizontal axis inclined to the longitudinal middle-line plane in terms of the initial transverse and longitudinal stabilities.

Directions of inclination which give the same initial stability.

Conjugate Stabilities.

Normals to surface of buoyancy, and character of equilibrium.

Properties of trochoidal and other waves.

Initial stability of small vessel on crest of trochoidal wave, or in hollow between two waves.

Early theories of resistance.

Admiralty Constants.

A perfect fluid—in what respects it differs from water.

Stream Line Theory.

Resistance to motion of a body of fair form deeply submerged, and also at the surface.

Formula, $\frac{v^2}{2g} + \frac{p}{w} + z = \text{constant}.$

Surface Friction Resistance: Experiments of the late Mr. Froude.

Data for calculating Surface Friction Resistance of a clean painted ship at given speed, and corresponding E.H.P.

Effect of foul bottom upon Surface Friction Resistance.

Rankine's augmented Surface.

Wave-making Resistance: law of comparison.

Deduction of Wave-making Resistance of Ship from that of Model with corresponding E.H.P.

The species of waves created by a ship in motion.

Effect of the positions of crests and troughs of transverse waves in relation to stern of Ship upon Wave-making Resistance.

Change in value of Wave-making Resistance with change of length of vessel at given speed.

Resistance Diagram.

Deduction of Resistance Diagram for Ship from that for Model.

Causes which augment resistance.

The several ways in which the I.H.P. is expended other than in the direct propulsion of vessel.

Ratio of E.H.P. to I.H.P.

Curves of I.H.P. and curves of Indicated Thrust.

Measured mile trials, and elimination of tide influence.

Investigation of formula $\frac{p}{y} = \frac{M}{I}$.

Application of above formula in determining stress upon beams of simple form, and upon deck beams under assumed Bending Moment.

Inaccuracy of the formula when applied to beams strained beyond the elastic limit.

Determination of the position of the neutral axis, and the Moment of Inertia of the section of a vessel amidships, assuming her to be on the crest of a wave.

The same, assuming the vessel to be in the hollow between two waves.

Determination of the stress at the gunwale, or on the bottom of a vessel, subject to an assumed Bending Moment.

Method of determining the Bending Moment amidships in the case of a vessel assumed to be in equilibrium on the crest of a trochoidal wave of her own length, the pressure in the interior of the wave being assumed to follow the same law as in still water.

The same, the pressure below the surface being assumed to be in accordance with the trochoidal wave theory.

Errors involved in the assumption that a vessel is in equilibrium on the wave crest while displacing her own weight of water.

Change in the magnitude of the stress at the gunwale when vessel is inclined away from the upright position, the Bending Moment being assumed to remain constant.

Effect upon longitudinal strength of fitting continuous erections of slight scantling upon the upper deck of a three-deck vessel.

Method of determining additional loading of spar and awning-deck vessels beyond that allowed in three-deck vessels, on the basis of equality of longitudinal strength.

Effect of the buckling of thin material in increasing the stress upon other parts of the structure.

Curves of Bending Moment for uniformly loaded deck beams, fixed at the ends, and with or without pillars at the middle line.

Beams under Tension or Compression and also subject to Bending Moment.

Transverse Strength of Ships.

Transverse Bending Moment due to water pressure on the bottom and sides.
Transverse Bending Moment due to weight of hull and cargo.
Thrust upon deck beams due to water pressure.
Effect of pressure of loose cargo, such as grain, upon a vessel's side in producing Bending Moment upon the bottom framing.
Graphic representation of variation in Transverse Stress in some simple cases.
The Ellipse of Stress.
Panting and other local causes of Straining in ships.
Investigation of the Stress upon a boat's davit under a given load.

In the afternoons the students of the third year prepare the midship section of a large merchant steamer, and make a detailed calculation to determine the position of the neutral axis and the moment of inertia for the case in which the vessel is on the crest of a wave, and also for the case in which the vessel is in the hollow between two waves, and they deduce the stress at the gunwale and on the bottom plating under an assumed bending moment. This is done for a vessel framed transversely, and also for one having a cellular bottom. Assuming the constancy of the bending moment as the vessel is inclined away from the upright position, the change in the magnitude of the stress at the gunwale, as the inclination changes, is also investigated, and represented by means of a diagram. The students then begin the design of a merchant steamer of given type to carry a specified weight of cargo and coals at a given speed. The necessary displacement and dimensions are first approximated to, the lines roughed out, the indicated horse power estimated, and the weight of hull and machinery calculated. Such modification in the dimensions as may be shown to be necessary to admit of the carriage of the specified quantity of cargo is then made, the lines are faired, and the plans drawn. The stability and other properties of the vessel are also investigated, so far as time will permit. In regard to this latter point I may add, that although instruction in the afternoons is specified in the calendar for two days of the week only, the drawing room which we owe to the liberality of Sir William Pearce is open each day of the week, and that students have largely availed themselves during the past session of the opportunities thus afforded of pursuing the work of the drawing classes.

I will not take up the time of the meeting by exhibiting or explaining diagrams which are already familiar to the members in illustration of the work done at the drawing classes. I propose, however, to refer to one or two pieces of work which are of some interest. With the view of impressing upon the students a sense of the importance of enclosed erections upon deck in improving the stability of a vessel, especially at large inclinations, as well as for the purpose of affording them some practice in the treatment of erections and other appendages in the calculation of stability, I have usually required each student to work out a curve of stability in the first place for a flush deck vessel, and afterwards for the same vessel with an enclosed bridge-house

amidships. The two curves for a sailing vessel 248 ft. × 38·6 ft. × 24·7 ft. moulded depth, with a displacement of 3,700 tons at the load draught, and with the centre of gravity 15·2 ft. above the top of keel, are shown upon Fig. 1 (Plate IV.). The vessel to which the curve A applies is supposed to have the sides and deck of a bridge-house, 50 ft. long, already fitted, as is commonly the case, and the mere completion of the bulkheads at the ends has the effect of changing the stability to that represented by curve B, the range being thereby increased from 66° to 84°, and the inclination at which the maximum ordinate is reached extended from 32° to 45°.

The importance of enclosed erections upon deck, extending to a vessel's sides, in improving the stability is not, I fear, so much appreciated by shipowners and others as it should be. In the event of the shifting of the cargo to any degree, the reserve stability remaining, in the case of the flush deck vessel, would be necessarily small, whereas the vessel having the enclosed bridge-house would be practically unsinkable from this cause, so long as water failed to find an entrance through hatchways or other openings. But while a want of appreciation of the increase of safety which intact erections upon deck afford, has probably been one cause of the fitting of erections which are almost worthless, so far as their effect upon the stability is concerned, and which may even, under some circumstances, by locking a quantity of free water in the vessel, prove a source of danger, the practice is no doubt due mainly to the operation of our tonnage laws, which deter owners from effecting this important addition to their vessels' seaworthiness, owing to the undue increase which the measurement of enclosed erections causes in the register tonnage, and thus in the current expenses, as compared with the corresponding increase of freight-earning power.

In Fig. 2 (Plate V.) I have shown a set of cross curves of righting moment, prepared by one of the students for the same vessel as above. These curves are drawn for inclinations of 30°, 60°, and 90°, and, as the members are aware, enable the ordinary curve of stability for a fixed displacement to be drawn with facility. As no great time has elapsed since the practice of constructing cross curves of stability began, it is hoped these may be of service in increasing the stock of available data. I may add that the drawing of a tangent to the curve at each of the calculated spots, as explained in a paper I read before the Institution in 1884, was found of great assistance in constructing the curves.

The next diagram, Fig. 3 (Plate IV.), to which I wish to direct attention is one which, I believe, will be new to the members. In calculating the stress borne by the material of a vessel amidships under a given longitudinal bending moment, it has been the practice hitherto to assume her to be upright, in which case the neutral axis of the section is a horizontal line. But when a vessel is rolling at sea the neutral axis constantly changes its inclination relative to the middle line, and the moment of inertia of the section changes its value also. Hence the length of the perpendicular from the gunwale

upon the neutral axis is increased on the one side and decreased on the other, and consequently the value of the stress at the gunwale becomes greater on the higher side and less on the lower than when the vessel is upright, and under the influence of the same bending moment. It may be said that a vessel crossing a regular series of waves in a line at right angles to the successive crests—the condition in which the longitudinal bending moment is assumed to attain its greatest value—would exhibit little or no tendency to roll, and this is no doubt true under the assumed conditions ; but we may well imagine a case in which a vessel rolling heavily changes her course, and thus becomes subject to the influence of a considerable bending moment when greatly inclined. It may also be of interest to note in this connection that in the case of a vessel which has any appreciable list, the lateral motion of the centre of buoyancy as she passes from crest to hollow, and from hollow to crest again, will of itself set up rolling motion. In constructing the diagram (Fig. 3) it was assumed that the bending moment when the vessel is inclined on the wave crest is the same as if she were upright. This is not precisely the case. As a matter of fact, the centres of gravity of hull and cargo in the fore and after bodies, and the corresponding centres of buoyancy, are no longer in the same vertical longitudinal plane, and we have transverse bending combined with longitudinal. But the value of the longitudinal bending moment cannot greatly change so long as the inclination of the vessel from the upright is moderate, and no great error is involved in assuming its constancy. The curves are drawn to represent the case in which the bending moment is great enough to cause a maximum stress of 8 tons at the gunwale when the vessel is upright.

As the vessel, whose dimensions are 380 ft. × 44 ft. × 31 ft. 10 in. from top of beam to top of keel at middle line inclines, the stress at the upper gunwale gradually increases until it reaches a maximum value of 9·36 tons, which is 17 per cent. greater than for the upright position, at an inclination of 28½ degrees, beyond which it begins to decrease. The corresponding curve for the lower gunwale is also drawn, and shows the stress at that part to decrease continuously with inclination. The diagram has been extended to include an inclination of 60 degrees, not because it is thought that vessels roll in practice through so large an angle, but in order that the character of the curves may be the better determined. The formulæ on which the calculations are based are given in an appendix to the paper.

Before bringing this paper to a close, I wish to offer a few remarks upon a subject to which I have given some little thought. Up to the present time the classes have been attended only by students who proposed becoming naval architects or marine engineers ; we have had no sons of shipowners, although a knowledge of some of the properties of ships would, I am convinced, be found of very great service to them in after life. It must not be supposed that I am putting forward a suggestion that those who are shipowners should also endeavour to become naval architects : I have no such

proposal to make. But the ability to deal promptly with many of the questions involving a knowledge of the properties of floating bodies that arise during a vessel's employment would be found of great advantage in the management of ships. Questions of trim, of the number of tons weight required to immerse a vessel one inch at any draught, and even that of the stability of ships, are really included in certain branches of hydrostatics and mechanics, may well form part of a liberal education, and may be as easily mastered by the shipowner as the naval architect. Such knowledge as I should like to see the shipowners of the future possess would prove of very great service in preventing the embodiment of mistaken ideas in new ships, and would enable them the better to evolve in a practical form sound views which experience may suggest for the improvement of their vessels. Many of the antiquated notions which still survive among us would soon disappear if our shipowners, who carry on their arduous duties with skill and enterprise, were to add to those many excellent qualities, which long ago established the supremacy of our Mercantile Marine, a better knowledge of the properties of ships.

APPENDIX.

Let M be the longitudinal Bending Moment borne by the vessel when upright on the crest of a wave, and suppose it to remain unchanged if the vessel be inclined. Let θ be the inclination of the vessel from the upright (Fig. 4, Plate IV.). The Bending Moment M may be resolved into a component M cos θ, acting in the middle-line longitudinal plane in the same way as when the vessel was upright, and M sin θ in a plane at right angles to the longitudinal middle-line plane. The effect of each of these components in causing stress at the gunwale may be separately estimated in the usual way, and the resultant stress will be their algebraic sum. Thus, if in Fig. 4, X X be the neutral axis corresponding with the component of the Bending Moment in the middle-line longitudinal plane, and Y Y the neutral axis corresponding with the component in a longitudinal plane at right angles to the former, y_1 the distance of the upper gunwale from X X, and x_1 its distance from Y Y, then using the formula

$$\frac{p}{y} = \frac{M}{I} \qquad (1)$$

we shall get

$$p = \frac{M\, y_1 \cos\theta}{I_1} + \frac{M\, x_1 \sin\theta}{I_2} \qquad (2)$$

where I_1 is the moment of inertia of the section about X X, and I_2 that about Y Y. Similarly the stress at the lower gunwale will be—

$$p = -\frac{M\, y_1 \cos\theta}{I_1} - \frac{M\, x_2 \sin\theta}{I_2}, \qquad (3)$$

x_2 being the distance of the lower gunwale from Y Y. The negative sign is used here because the Bending Moment M cos θ tends to place the lower gunwale under tension, as the diagram is drawn, while M sin θ tends to place it in compression.

The general expression for the stress at any point (P) of the section on the right hand of Y Y is given by the equation—

$$p = \frac{M\, y \cos\theta}{I_1} - \frac{M\, x \sin\theta}{I_2}, \qquad (4)$$

x and y being the co-ordinates of the point, and to determine the inclination of the actual neutral axis corresponding with the inclination of the vessel, we must put $p = 0$, since the stress is *nil* at that place. We have thus—

$$\frac{M\, y \cos\theta}{I_1} = \frac{M\, x \sin\theta}{I_2}, \qquad (5)$$

from which we get—

$$\frac{y}{x} = \frac{M\, I_1 \sin\theta}{M\, I_2 \cos\theta} = \frac{I_1}{I_2} \tan\theta, \qquad (6)$$

also $\frac{y}{x} = \tan\phi$, where ϕ is the inclination of the actual neutral axis to X X. Hence

$$\tan\phi = \frac{I_1}{I_2} \tan\theta \qquad (7)$$

To find the inclination at which the stress at the upper gunwale has a maximum value, we must differentiate the expression in equation (2), with respect to θ, and equate to zero. Thus—

$$\frac{d\,p}{d\,\theta} = -\frac{M\, y_1 \sin\theta}{I_1} + \frac{M\, x_1 \cos\theta}{I_2} = 0,$$

from which

$$\tan\theta = \frac{x_1\, I_1}{y_1\, I_2}$$

In the example given in the paper the inclination at which θ attains its maximum value is $28\frac{1}{2}^\circ$.

DISCUSSION.

Professor F. Elgar, LL.D. (Vice-President): My remarks, which will be very brief, will be limited to that portion of the paper which deals with the course of instruction given in naval architecture at Glasgow University; and what I have to say upon this will be very little, because Professor Jenkins' paper is essentially not one that raises questions for discussion. It is not put forward, I take it, with that object, but because of the interest which has always been taken by this Institution from its commencement in the very important question of education in the science and practice of naval architecture. It is very useful to members of the Institution to have upon record in the Transactions a full and clear description, such as this, of the course of instruction now given in this subject at Glasgow in connection with the Mercantile Marine. It will be especially useful to those members of the Institution, and to others, who are interested in young men that desire to educate and qualify themselves for becoming naval architects; and it will enable anyone to judge very fairly of the nature and scope of the instruction that is obtainable in the University of Glasgow. If this paper were to be treated as one for discussion, I should merely say, with reference to it, that I fully endorse the views expressed by Professor Jenkins upon the general question of the study of naval architecture, and especially those he has so ably put forward respecting entrance examinations and the advantages of a study of the principles of naval architecture to those who may some day have to deal practically with

ships from a shipowner's point of view. The principles now set forth by him are, in the main, such as I myself acted upon when I had the honour to fill the chair of naval architecture at the University. There is one important point in connection with the subject of this paper that it is desirable, I think, to dwell upon, because the success of such an institution as an University chair of naval architecture depends very materially upon it, and that is, the help that has been given in the foundation and in the carrying on of the work of the chair by various benefactors to the University. First and foremost, of course, is Mrs. John Elder, who came forward about five years in a most liberal and public-spirited manner, at a time when a general feeling was being felt and expressed with regard to the want of better means of education in Glasgow in the higher branches of naval architecture. Mrs. Elder, who now has no personal interest in the profession, but who knew, as I have heard her say, that if the late John Elder had been living he would have been desirous to do something for the benefit of students of naval architecture and marine engineering, such as he had felt the want of in his own early days, came forward in his place, and provided the endowment for the chair. That was, of course, sufficient to ensure the commencement of the work, but, even after that, more remained to be done. The Glasgow College, although a very large building, is devoted to very many purposes, and there was very little space available in it for the work of the new chair of naval architecture. I am bound to recognise the very generous and kindly manner in which the Principal and the Professors of the University received me when I came amongst them, and the manner in which they went out of their way to assist me, whenever and however possible, in supplying the deficiencies which existed. The necessary class-rooms were lent to me for various purposes by the professors to whom they belonged, so that during the first year of the work we did not suffer any practical disadvantage; but the work of the chair could never have been carried on satisfactorily and completely but for the erection of the present building which is devoted to that purpose, with its suitable class-rooms. That we owe to the generosity of Sir William Pearce. Sir William Pearce has conferred a very great boon upon the University and the profession by the liberal manner in which he has acted in providing this accommodation. There are not only these two principal benefactors to whom our thanks are due, but a great deal is also due to the manner in which the shipbuilders and the engineers of the Clyde have always been ready to help in supplying the many wants which arise in commencing and carrying out a system of instruction such as this. Shipbuilders have helped us very materially, at many times, by providing various apparatus, models, and appliances, such as are useful for teaching purposes; and, what is very important, we have always found that when students have come to Glasgow, and have wanted to go through a summer course of practical instruction in the shipyards or engine works, as well as the scientific course of instruction in the University during the winter, there has been some shipbuilder or marine engineer public-spirited and generous enough to allow them to work in the drawing office, shipyard, or engine shop during the summer months. I should also refer to the matter of scholarships. Messrs. J. & G. Thomson, of Clydebank, founded a scholarship in 1885 of the annual value of £10, tenable for two years. It is open to young men not under 18 years of age, who have been employed at least three years as working apprentices or in the drawing offices of shipbuilding or engineering works at Clydebank, Yoker, or Dalmuir. In addition to the value of the scholarship, Messrs. Thomson pay any student from their own works who may obtain it at the same rate during the time he is studying in the University as they would do if he were at work with them. The foundation of scholarships is of the greatest possible value, of course, in helping young men to obtain the advantages of the higher education from which they would otherwise be debarred through want of means. There are other shipbuilders and engineers who, I know, are ready to do for the districts in which they are interested whatever may be useful in the way of providing scholarships for the

encouragement and help of students; and I am sure we shall all agree that anyone who may so help will be a true benefactor to our profession, and to poor students who have only their own efforts to depend upon. Such a body as Lloyd's Register Society might with great advantage endow scholarships that would enable students from all parts of the country to obtain the education that is now given in Glasgow. I do not think it remains for me to say more on this paper. I agree, as I have already said, with the views expressed by Professor Jenkins upon the general question of the study of naval architecture; and I will only add that I am quite sure the members of this Institution will agree that the University of Glasgow is to be congratulated upon having a gentleman of Professor Jenkins' ability and attainments in the chair of naval architecture, and that this Institution may feel every confidence that the profession of naval architecture is very worthily represented by him at the University.

Mr. Benjamin Martell (Vice-President): My Lord, after what Professor Elgar has said with reference to this paper, it would not become me to say many words, and I should not attempt to do so were it not for one subject. You will remember that in the paper which I had the honour of reading yesterday in this building, I drew attention to the great benefit which naval architects have derived from the late Mr. Froude's researches with the experimental tank. It occurred to me afterwards—and although I do not know in reality that it is so, yet I think we may fairly take it—that the great success that has been realised in that beautiful vessel built down at Dumbarton by Messrs. Denny Brothers for the Dover and Ostend trade—for I understand she is realising 21 knots, an unprecedented speed for a vessel of that kind—is mainly due to the enterprise and liberality which they displayed in setting up an experimental tank on their premises. That is merely an illustration to show the benefit, as I pointed out, to be derived from experimenting still further in that manner. I do not think one can emphasise too much the great necessity for, and the great advantage to be derived from, a course of education such as is pointed out here by Professor Jenkins in his paper as being given to students; and if, in addition to that, some of the liberal-minded gentlemen, professional men in this city, would only realise the importance of it, and contribute amongst themselves to place in the University an experimental tank similar to that which a private firm has done for its own use, the benefit that would be derived by students, and through them by the profession in general, cannot in my opinion be over-estimated. I only wish to make those remarks. I do think that the question should be put before the public in the strongest manner possible.

Mr. Archibald Denny (Member): My Lord, during the time Professor Jenkins has been reading the second part of his paper, I have endeavoured to read over the list of work done at the College, which he allowed to be taken as read. The work at the College appears to me to be very well arranged, and to reflect great credit upon Professor Jenkins. I had the advantage of attending the three years' course at the Royal Naval College under Mr. White, and while I derived great benefit from the course, I would have been in a position to benefit much more had I first had a mathematical training at either the Glasgow University or Cambridge; because the work at the Royal Naval College requires a high mathematical training, and students are supposed to join the College with a very much greater knowledge of mathematics than outside students are usually in the possession of. Boys leaving school as I did at the age of sixteen do not possess this knowledge. Previous to going to Greenwich I served three years' apprenticeship in the Leven Shipyard, working as a tradesman during the day and studying mathematics at night; but after nine hours' manual labour in the yard the brain is not very active in the study of mathematics. I think this course under Professor Jenkins fills up an important gap between the more or less simple course of instruction in naval architecture

under the South Kensington authorities and that at the Royal Naval College, and I trust that as time goes on more and more advantage will be taken of it. With regard to the latter portion of Professor Jenkins' paper, in which he gives samples of the work done under him at the college, there are one or two points I would like to notice. The calculations made for the strain on the gunwale of a ship when rolling at sea, are no doubt very interesting and instructive, but it seems to me in a shipyard office it is quite sufficient to calculate the strains on a ship supposed upright in waves of her own length, and thus obtain the strain factor (for it is only a factor and not a real strain) without complicating it further by assuming the ship to be in an inclined position. I quite sympathise with what Professor Jenkins says as to the necessity for shipowners knowing more theoretically about the vessels they own than they do at present. I think my firm have done a good deal in this direction, in handing to owners the Technical Qualities book, schemed out under the direction of my late brother, Mr. William Denny, the usefulness of which was I think increased by the additions made by myself two years ago, and which formed the subject of a paper read by me before this Institution in 1887. With your permission, my Lord, I would like to inform this meeting that the inclining diagrams then spoken of have since been used on board the S.S. *Tainui* with perfect success. This ship on one of her voyages was inclined in New Zealand before leaving for home. The diagrams taken, together with the information supplied by the captain of his treatment of the ship, show that at one time during the voyage the metacentric height became as little as 0·5 ft., and that she was then found to be rather tender. On starting on her voyage, and again after the captain had discovered that she was tender and had let in more water ballast, she had a metacentric height of rather more than 0·8 ft., and righting arms at 30° and 45° of more than 1·0 ft., which are the limits we fixed in dealing with this ship. She performed her homeward voyage successfully, and the captain reported the voyage an extremely comfortable one. I think this is a very valuable piece of information. With regard to what Mr. Martell said as to the success of the *Princess Henriette*, no doubt she has been extremely successful, and I thank him for the kind way in which he has referred to our achievement. The amount of labour and consideration given to her design was extremely great, and we of course used the tank in the investigations. He has recommended that a tank should be attached to the University, and I quite agree with him. There has been some talk of a co-operative tank, but I do not think this would be a success. I feel certain that a tank, to be of real and direct use, must belong to one individual, and he must have the sole right of access to all data obtained in it. A co-operative tank would only be of indirect use to the co-operators, as each one would only have the right of access to the data obtained from his own models. This I say from my experience of our tank. In conclusion I think, my Lord, Professor Jenkins deserves our thanks for the very valuable paper which he has contributed.

Professor James Thomson (Visitor) : My Lord, I have little to say after the very interesting discussion which has just been held on Professor Jenkins' paper, not possessing myself such experience in naval architecture as would justify my saying very much. But, my Lord, I have attended with great interest to Professor Jenkins' paper, and would say that I am very much satisfied with the course he is taking in arranging and organising the teaching for his students. In reference to the information and suggestions which he has put forward in favour of ready admission of students to the Naval Architecture Department in the University, without the imposition of a previous entrance examination, which would be a hindrance to many deserving young men as to their coming forward to offer themselves as students, and would lead to the rejection of others, I wish to give him my cordial support. I myself entertain strong opinions against the introduction of obstructive difficulties in the way of persons coming either from school on the one hand, or from workshops on the other, as to their

admission to learn what can be taught in the University: difficulties, I mean, such as are interposed by alarming or deterrent entrance examinations. I think the proposing student can himself, with a little advice from the Professor or from other friends, judge better than an examiner, practically speaking, as to whether he be sufficiently prepared to profit by entering the classes or not. An examination which may be really quite too easy for securing high mathematical attainments, might be exceedingly difficult to the entrance student, and might prevent a great many from coming who really could profit by the teaching, and would be willing to be examined, and would answer well in examinations after some of the teaching, rather than before the teaching commences in the University. With regard to the point with which Professor Jenkins concluded—the advisability, in many cases, of young men connected with the shipowning interest taking some parts or the whole of the course in the University—I think it is one very much worthy of commendation.

Mr. W. H. White, F.R.S. (Vice-President): My Lord, if no other gentleman is desirous of speaking, I should like to say a word or two before the discussion closes. Eleven years ago, I think, in this room, I read a paper, to which Professor Jenkins has alluded. A great many shipbuilders who were then present were disposed to think I was dealing with a matter that had little interest or concern for them. Since that time, however, there has been an enormous change in the attitude of shipbuilders in this country with regard to the application of scientific method in the conduct of their work, a change which I think has been gradual, and therefore can scarcely be appreciated, except by looking back through an interval of time such as Professor Jenkins has mentioned to-day. Standing here, of course, one naturally thinks of what happened eleven years ago; and I remember well—I shall never forget—the cordial manner in which my friend William Denny spoke words of encouragement and assistance in the effort I was then making to interest those engaged in practical work in scientific methods, words which were of infinite value to me. I believe that William Denny's influence since then has been of the greatest value in assisting the efforts of shipbuilders generally in developing that scientific method which is now so common in the shipyards of the country. We then stood in the position of having at the Royal Naval College at Greenwich, the only place in this great country where instruction could be given in the higher branches of naval architecture. We had endeavoured, I had personally endeavoured, to associate with that higher instruction classes of a more elementary character, into which could come the sons of shipbuilders or draughtsmen, to take up those more practically useful subjects which would in their hands be brought to bear upon their daily work. I was sorry at the time that we failed to introduce those elementary classes at Greenwich. Standing here to-day, I can say that I am glad, because it is far better—far better in every way—that in a great shipbuilding centre like this of Glasgow there should be the local means of education which the University of Glasgow in its chair of naval architecture now affords. I sincerely hope that in the College of Science at Newcastle there may arise, not a rival institution, but a sister institution, which shall there do similar work for the North-East Coast, which must always find a warm place in my heart. In the development of the College of Science there, it is proposed to establish a course of instruction of a similar character to that which Professor Jenkins so ably conducts here; and I am sure our friends in Glasgow will not think of the people on the North-East Coast as in any way trenching on their province if that idea should be carried into practical effect. There is one other thing being done which this meeting may not know of, which indicates the great growth and the interest taken in this form of education in naval architecture. The old Shipwrights' Company of London, which was nearly defunct a few years ago, is now (within the limit of its means) endeavouring to encourage in the Port of London the study of naval architecture at the Science Classes which are there held; and if the scheme

is carried out, as I hope it will be, there will be some more definite attempt at elementary instruction in naval architecture in the Port of London than can at present be found. Coming to Professor Jenkins' own paper, and to the course of study which he has there described, I consider the whole arrangements most admirable. I think it is a matter of the greatest good fortune to this chair of naval architecture in Glasgow that in the first place it should have been accepted by my old friend and fellow student Mr. Elgar, who gave the initiative and direction to the course of study, and that he should have been followed by my friend and former pupil, Professor Jenkins, a man who in the Admiralty service, and at Lloyd's, and in other ways had obtained the most varied acquaintance with all the conditions of shipbuilding. I agree with him, too, that for the purposes which are had in view in Glasgow, it is desirable to let the door of entry stand wide open. The objects to be aimed at at the Naval College are, of course, different from those to be attained here in Glasgow; and my old pupil, Mr. Archibald Denny, has hit the nail on the head when he says that for that course of study, which, of course, is not necessary for the great bulk of those engaged in the operations of shipbuilding, a preliminary mathematical training is essential. But for the average students who enter at the Glasgow University, I quite agree that in dispensing with an entrance examination, and giving to students the best instruction which their previous knowledge and experience permits, the true procedure has been followed. As regards the knowledge of the shipowner also, and the sons of shipowners, the suggestion of Professor Jenkins seems to me to be one of the highest value. Perhaps I may be permitted to go a step further, and to say if the officers of the Mercantile Marine could also take a short course of study in this College it would be found of the greatest value. The one thing I was able to do at the Naval College, in addition to the higher training, was to establish classes in naval architecture for naval officers. Naval officers, as is well known to gentlemen here, have considerable periods of leisure—enforced leisure, and during those periods they have the opportunity of attending at the College and of there studying. I think I can appeal to Captain FitzGerald, and to many other officers who have been at the College, to this effect, that the instruction which we have been able to give there to naval officers has been of the greatest value to them afterwards in the command of their ships. One gentleman told me of a case where his gunboat had been ashore in an African river. They proceeded to lighten the ship, and lightened her of everything portable, but still she remained there on the bank. He told me that if he had had the simple instruction which he was then receiving he would not have attempted to put anything over, but would have waited until the water rose again. So that I think in his case the cost of his instruction has entirely been reimbursed to the State. I have nothing more to say, except to express my hearty thanks to Professor Jenkins for the kind way in which he has alluded to myself. I have been, I may say, all my life connected, either as pupil or as teacher, with the subject of naval architecture, and I do most heartily congratulate the city of Glasgow on the perfect success of this chair of naval architecture, and wish it a prosperous future.

Captain C. Penrose FitzGerald, R.N. (Associate): My Lord, while I fully acknowledge the advantages which we naval officers have derived from the instruction at the Royal Naval College, which Mr. White has alluded to, I think it would be very interesting if Professor Jenkins would explain what he means by "many of the antiquated notions that still survive among us would soon disappear if our shipowners, who carry on their arduous duties with skill and enterprise, were to add to those many excellent qualities, which long ago established the supremacy of our Mercantile Marine, a better knowledge of the properties of ships." Mr. White gave us a ludicrous description of a captain who hove his cargo overboard, instead of waiting for the tide to rise. That, I should imagine, was a somewhat elementary error in seamanship. If I am to understand by Professor Jenkins' statement

that all the knowledge we have gained as seamen by centuries of accumulative experience is to be swept away by a few mathematical calculations, I, for one, demur. With regard to these elaborate mathematical calculations, it is no secret now that some of our recent men-of-war have not come out in practice exactly as they were expected to. There are the *Ajax* and *Agamemnon*, for instance. I will not say they have not come out in accordance with the mathematical calculations, for I am not acquainted with what those calculations were; but they have certainly not come out in accordance with the requirements of practical seamanship.

Mr. W. H. White: Just one word of explanation. It was not a question of the rise and fall of the tide.

Professor P. Jenkins (Member): My Lord, in replying, I will notice the remarks of Captain Fitzgerald first. With regard to antiquated notions – the existence of which Captain Fitzgerald doubts—I may say that I think we heard some of them yesterday. Gentlemen who were present yesterday, and who followed the discussion on Mr. Martell's paper, recognised some of the antiquated notions then. But perhaps I may be allowed to just refer to one notion which is very common among ship captains and others. I have heard it said over and over again that when cargo is being put on board a vessel she will stubbornly resist further immersion until a certain point is passed—until, in fact, she had found her "bearings"; and after that, any cargo put on board immerses the vessel far more rapidly. If we could destroy that notion I think we should be doing some good. There are a great many others with which I will not now trouble you. Dr. Elgar referred to the assistance which at all times we received from the shipbuilders on the river. I am glad to have the opportunity of cordially endorsing what he said. I have always found the shipbuilders on the river most happy to assist me in carrying on my duties whenever it has been my pleasure to have to ask them for assistance. Mr. Martell referred to the experiment tank. That is a matter which I raised some time ago. I am still of opinion that if we could establish an experiment tank in connection with the University, it would be of immense advantage, not alone to students—although they would reap much advantage—but to the shipbuilders also. I do not quite follow Mr. Denny that if such a tank were provided by a combination of shipbuilders it would lose much of its value. I do not at all agree with that view. I believe, on the contrary, that if we had a tank formed in that way by the co-operation of shipbuilders, we should be able to help them all, and very materially. When a shipbuilder contracts for a new vessel to go at a very high rate of speed, and wants a curve of resistance for his design, he can get it from such a tank, and his prediction of speed would be far more certain than the guess he would be obliged to make if there were no such tank. With regard to Mr. White's remarks as to the education of officers of the Mercantile Marine, I may say that we should only be too glad to see them at the University; but we must remember that officers of the Mercantile Marine have not that leisure which officers of the naval service have; they are not so long and so often on half-pay. If that difficulty could be got over—if we could succeed in drawing officers of the merchant navy from their ships, it would give us great pleasure to undertake the charge of them. In conclusion, I have to thank you all for the very kind way in which my paper has been received.

The President: Gentlemen, it gives me the greatest possible pleasure to rise and convey to Professor Jenkins—which I am sure you wish me to do—our thanks for his admirable and instructive paper. I think Professor Jenkins will also agree with me that the encomiums, coming from such men as his distinguished predecessor, Professor Elgar; the Chief Constructor of the Navy, whose services—public and national services in connection with the Naval College at Greenwich the country will always recognise with gratitude; and last, but not least, Professor Thomson—that encomiums from such

sources as these are worth a great many words indeed. I am now speaking on behalf of the Institution of Naval Architects. Our highest, and probably our most valuable, function is to bring forward and to encourage our young men in the important studies of marine engineering and naval architecture, and I trust and hope it will be an encouragement to the young men, not only of Glasgow, but of the United Kingdom generally, to observe the early but the well-merited promotion that one of our most distinguished young members has lately received in being appointed to this important chair. I speak now with some few years' knowledge of Professor Jenkins. I remember--and we all remember very well—that on two or three occasions he read most interesting and valuable papers in connection with another very distinguished young man, Mr. Thomas Read, who, I believe, is known to some who are present here, and I remember well also the ability with which they invariably joined in our discussions. I am very happy indeed to see such a career open to him, and I am quite sure you have secured in him a man who will be of great service to the University with which he is now, I hope, so inseparably connected. I have thought it fair to make these very few observations because I have watched him with very great interest indeed, and I am sure that every member of the Association will be glad to meet our young friend Professor Jenkins in his new and honourable position.

THE FIRST CENTURY OF THE MARINE ENGINE.

By Professor Henry Dyer, C.E., M.A., Member.

[Read at the Thirtieth Session of the Institution of Naval Architects, July 25th, 1888; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

In various Scotch newspapers for October, 1788, there appeared an account of an experiment, which was said to be "no less curious than new." It was stated that "on the 14th inst. a boat was put in motion by a steam-engine upon Mr. Miller of Dalswinton's piece of water at that place. That gentleman's improvements in naval affairs are well known to the public. For some time past his attention has been turned to the application of the steam-engine to the purposes of navigation. He has now accomplished and evidently shown to the world the practicability of this, by executing it upon a small scale. A vessel 25 ft. long and 7 ft. broad was, on the above date, driven with two wheels by a small engine. It answered Mr. Miller's expectations fully, and afforded great pleasure to the spectators present. The engine used was Mr. Symington's new patent engine." It was further stated that a "more complete, successful, and beautiful experiment was never made by any man at any time, either in art or science. The vessel moved delightfully, and, notwithstanding the smallness of the cylinders (4 in. in diameter), went at the rate of five miles an hour." It continued to ply for some days for the amusement of the projector and to the astonishment of the country people, who assembled from all quarters to witness the wonders of a "boat driven by reek." Fifty years later, that is in 1838, the *Sirius* and the *Great Western* crossed the Atlantic, both arriving at New York on the same day, April 23, the *Sirius* in the morning and the *Great Western* in the afternoon. We are thus in this year 1888 in a position to celebrate the centenary of the marine engine, and at the same time the jubilee of trans-oceanic steam navigation. I have no intention of entering into the various historical disputes which have taken place regarding both of the above dates. I shall simply take them as convenient starting points from which we may make a rapid *resumé* of the chief steps in the development of the marine engine and steam navigation; in fact, to take stock of the most important advances which have from time to time been made, so that a distinct idea may be formed of our present position.

Such stocktaking is as necessary in different departments of knowledge as it is in business, and the visit of the Institution of Naval Architects to the Clyde, the greatest shipbuilding centre in the world, in the hundredth year of the marine engine, and the fiftieth of trans-oceanic steam navigation, seems a suitable occasion for a rapid review of marine engineering. To do full justice to the task, however, would take much more time than I have had at my disposal since I was asked to undertake it, and more than you would be willing to spare on such an occasion as this. A brief outline is all that can be attempted, and even that must be to a large extent confined to Clyde practice. As the President has claimed for Glasgow the honour of being at one and the same time, the birth-place and the cradle, the nursery and the high school of steam navigation, I am sure that this method of treating the subject will not excite the jealousy of Members from other districts, my object being not so much to discuss the claims of individuals as to illustrate the chief stages in the development of the marine engine.

It is not necessary that we should enter into the details of the development of the steam-engine apart from its application to the propulsion of vessels; it is sufficient to note that in the first steam-engine which was at all of a practical nature, and resembling those at present in use, namely, that designed by Papin, the boiler, cylinder, and condenser were combined in one; that the next step was taken by Newcomen, when he separated the boiler from the cylinder; while engines of the same type as those which at present exist, were designed by Watt in all their essential details when he separated the condenser from the cylinder. The tendency to multiply parts still, however, continues, and instead of the steam being used in one cylinder, as it was by Watt, it is now very often used in two, three, or more cylinders, each with separate organs of admission and exhaust, and requiring a multiplication of the parts of the mechanism.

The credit for the design of the engine and boat used at Dalswinton seems to be jointly due to Patrick Miller, James Taylor, and William Symington. John Scott Russell has remarked that "the creation of the steamship appears to have been an achievement too gigantic for any single man. It was produced by one of those happy combinations in which individuals are but tools working out each his part in a great system, of the whole of which no single one may have comprehended all the workings." After a long and patient examination of the claims of each candidate, Mr. Scott Russell came to the conclusion that the art of steam navigation was the joint invention of the three men who have been named, and that to their efforts the world owes its present advantages. Similar remarks apply with even greater force to the later stages of the development of the marine engine, as to many minds seem to be due the ideas which bring about improvements, although one man may be fortunate enough to make them commercially successful. In the case we are considering the combination of the three

men concerned in the work was well designed to bring about good results. Miller was a patriotic and wealthy experimentalist, Taylor a sagacious projector, and Symington an ingenious and experienced mechanic. The second steamboat was constructed at Carron in 1789 by the same three men. It was 60 ft. in length, and was fitted with engines having cylinders 18 in. in diameter. At the first trial the boards of the paddles gave way. They were, however, repaired, and on December 26, 1789, the experiment was repeated, and a speed of nearly seven miles an hour obtained. The boat, however, was of too slight a build to be used permanently for traffic; and as soon as the experiments were over the engines were taken out and deposited at Carron Works, and the vessel used as a pleasure boat by Mr. Miller.

The first really practical steamboat, the *Charlotte Dundas*, was designed by Symington in 1801, and tried on the Forth and Clyde Canal early in 1802. It was propelled by what was essentially a Watt double-acting engine, although designed and patented by Symington. It was a horizontal direct-acting engine, and appears to have been the first ever made; the piston-rod and connecting-rod of which were coupled direct to the crank arm, the lever being dispensed with. It was able to tow two vessels, each of 70 tons burthen, a distance of twenty miles against a strong head-wind in six hours. The proprietors of the Canal, fearing injury to its banks, declined to adopt the new system of towing, and we hear of nothing further having been done by Symington.

We have now to cross the Atlantic for the next developments of steam navigation. John Fitch, an ingenious Connecticut mechanic, had for many years experimented with different designs of engines, and from 1787 till his death, in 1798, he built several steamboats, but in all his attempts he was unfortunate. Various other workers were busy in America about the same time, or shortly after, most prominent among whom was Robert Fulton, who, although American by birth, was Irish by parentage. At the age of twenty-one, by his own exertions he had acquired considerable skill in mechanics and as an artist. Coming to England in 1786, he spent some time in mechanical pursuits; and arriving, as he did, just before the trials of the Dalswinton and Carron boats, his attention was naturally directed to them, and about them he collected a considerable amount of information. It was not, however, till some years later that he seriously took up the subject of steam navigation. After spending some years in England, he migrated to Paris, where many projects occupied his time, especially submarine warfare, locomotion, and explosions. In 1801 he directed the attention of Livingstone, the American Minister at the Court of France, who had himself made many experiments on the subject, to the importance of steam power in the navigation of the lakes and rivers of their own country, and the two agreed to co-operate.

Fulton went about the work in a very thorough manner, and made many experiments on the resistance of models of different kinds at various speeds, and guided by the results of these, he completed a steamboat which was tried in the River Seine in

the spring of 1803; but the vessel proved too weak for the heavy machinery, and it broke in two and sank to the bottom of the river. The machinery, however, was little injured, and the hull being reconstructed, a trial was made on the 9th of August, 1803, and a speed of about 4½ miles an hour attained. Disappointed in obtaining pecuniary aid from the French Government, in 1804 he crossed over to England, and ordered an engine from Boulton & Watt of 2 ft. diameter of cylinder, and 4 ft. stroke, which in its design was a modification of the ordinary type of engine made by that firm. Fulton and Livingstone, on their return to America, constructed a vessel named the *Clermont*, which was launched in the spring of 1807, and employed the Watt engine to propel it. This vessel, which had many of the characteristics of the American river steamer of the present day, was larger than any steam vessel which had hitherto been constructed, being 133 ft. long, 18 ft. broad, and 9 ft. deep. The boat on its trial ran a distance of 150 miles in thirty-two hours, and returned in thirty hours, and this, no doubt, was the first voyage of considerable length ever made by a steam-vessel.

Fulton built a considerable number of other vessels immediately after the successful trial of the *Clermont*, and in 1812 he designed the first steam-vessel of war, which was launched on 29th October, 1814. The *Fulton the First*, as the vessel was called, was considered of enormous dimensions at that time. The hull was double, 156 ft. long, 56 ft. broad, and 20 ft. deep, measuring 2,475 tons. On her trial trip she steamed 53 miles in 8 hours and 20 minutes, and when her armament and stores were on board, she made 5½ miles per hour. Although we cannot place Fulton among the highest class of inventors, still his name deserves to be honoured for having made steam navigation a commercial success. Among the other Americans who did much to advance marine engineering in its early days, time will only permit the mention of those of John Stevens, of Hoboken, who not only did much to improve the designs of engines, boilers, and propellers, but also of the forms of vessels; and of his son, Robert L. Stevens, who afterwards became known as the designer and conductor of the Stevens battery.

The part taken by Fulton and Livingstone in America was occupied in Britain by Henry Bell, of Helensburgh, on the Clyde, who turned to useful account the experience of Miller, Taylor, and Symington. He had the further good fortune to associate with himself an able shipbuilder and an ingenious engineer. In 1812 he contracted with John Wood, of Port Glasgow, to build the hull, and with John Robertson, of Glasgow, to make the engines of the *Comet*. This vessel was 42 ft. long, 11 ft. broad, and 5 ft. 6 in. deep, and the engine of three-horse power had a cylinder 11 in. in diameter, with a stroke of 16 in. At first she was fitted with two pairs of paddles driven by spur gearing, but this arrangement proving unsatisfactory, she was lengthened to 60 ft., and fitted with a single engine which drove a single pair of paddles. The speed attained seems to have been about six miles an hour. Mr. Bell had associated with him in his

experiments John Thomson, engineer, Glasgow, who, feeling himself aggrieved when Bell declined to allow him to become a partner in the speculation, got John Wood to build a vessel 51 ft. keel, 12 ft. beam, and 5 ft. deep, which was named the *Elizabeth*, and made on an average nine miles an hour, and was able to eclipse Bell's *Comet*. The *Elizabeth* was thus the first remunerative steam vessel in Britain.

For a record of early British steamers reference must be made to special historical treatises and papers,* our time only allowing us to notice a few of the chief of them. Among the shipbuilders the names of Wood, Steel, Scott, Denny, and Caird, and among the engineers those of David and Robert Napier, all of the Clyde, stand pre-eminent. Of the first of these Mr. Robert Duncan has remarked that "he was the father of all that is best in the style of our ships, and truest in the practical application of science in the shipbuilding of Great Britain," while of David Napier, Mr. Scott Russell was of opinion that from the year 1818 until about 1830 he effected more for the improvement of steam navigation than any other man. He established deep sea communication by steam vessels and post office steam packets, first in 1818 between Glasgow and Belfast, by the *Rob Roy*, a vessel of 90 tons burden and 30-horse power built by William Denny, of Dumbarton, which after plying for two winters between the above-mentioned ports with perfect regularity and success, was used as a packet between Dover and Calais. About the same time he established a line of steamers between Liverpool, Greenock, and Glasgow. The *Robert Bruce*, of 150 tons, built by Messrs. Wood, the *Superb*, of 240 tons, and the *Eclipse*, of 140 tons, were all engined by David Napier, and their good proportions and construction did much to establish steam navigation on a firm basis and render it an object of national importance, and it, from this time, underwent great and rapid improvement. The construction of the *James Watt* in 1822 marked a decided step in advance. It was of 448 tons measurement, and was built by the Messrs. Wood, and in form, strength of construction, and speed, was much before every vessel of her day, having a speed of 10 miles an hour. Her two engines of 50-horse power were by Boulton and Watt, and were geared between the crank and the paddle shafts. From the time of the construction of the *James Watt* a gradual increase in the size and improvement in the design of the ships and engines took place, until what was called at the time the Leviathan class was reached.

As early as 1819, an American vessel, the *Savannah*, had crossed to Britain, partly sailing and partly steaming, while in 1833 the *Royal William* crossed from Quebec, but it was not till 1838 that Transatlantic navigation was established on such a basis as to

* Among the latter may be consulted Miller "On Early Clyde-built Steamers," Trans. Inst. of Eng. and Shipbuilders, Scot., vol. xxiv. p. 49; Sandham "On the History of Paddle-wheel Steam Navigation," Proc. Inst. Mech. Eng., 1885, p. 121. The interesting handbook for the collection of Marine Engine models at South Kensington, by Mr. Holmes, the Secretary of this Institution, may also be read with advantage. A few of the particulars in this paper have been taken from proofs of this handbook, which have been kindly sent by Mr. Holmes.

prove that it would be commercially successful, as was done by the voyages of the *Sirius* and the *Great Western*. The *Sirius* was built by Messrs. Menzies, of Leith, in 1837, and her engines, which were of the side lever type, were constructed by Wingate & Co., Glasgow, her tonnage being about 700 tons and her horse power 250. The *Great Western* was the first steamship specially constructed for the Atlantic trade. She was built at Bristol by Mr. Paterson, and her dimensions were 212 ft. in length between the perpendiculars, 35 ft. 4 in. breadth of beam, and 23 ft. 2 in. depth of hold; registering 1,340 tons, builders' measurement. Her engines, which were side lever, and 440 horse power, were constructed by Maudslay, Sons & Field, of London, having cylinders 73½ in. in diameter and 7 ft. stroke, making twelve to fifteen revolutions per minute. The *Sirius* and the *Great Western* arrived in New York on the same day, April 23, 1838, the latter having performed the voyage in four days less than the former.

The practicability of Transatlantic steam navigation being thus established, many large steamships, both for commerce and war, were built in rapid succession, and well-known lines were established. Among these need only be named the Cunard Line, which owed so much to the genius of Robert Napier; the Inman Line, with which Tod and McGregor were associated in the engineering department; the Collins, an American line; and, somewhat later, the West Indian Mail Steam Packet, the Pacific Mail Steam Navigation, the Peninsular and Oriental Companies, and the Anchor and the Allan Lines, all of which furnished many excellent examples both of ships and engines.

For the first twenty years after the establishment ot ocean navigation, the side lever engine was employed almost entirely in the larger mail packet companies, and was essentially Watt's engine, modified in some details. The Americans used, and to a large extent still use, the ordinary beam engine, for paddle steamers, but in Britain, in order to economise space, and keep the centre of gravity of the engines low, they were inverted, and thus became what were called side lever engines. Some of them were magnificent specimens of architecture, but engines of this type were by no means self-contained, the keelsons and framing of the vessels being largely relied upon for resisting the stresses arising from the action of the engines, and of course under such conditions a low pressure of steam and uniformity of motion were matters essential to their safe working. The pressure of steam was generally from 3 to 5 lbs. and seldom exceeded 10 lbs. on the square inch above the atmosphere, while the space occupied in the hull by the engines and boilers was nearly one-third of the ship's length. No trustworthy figures can be found to show the consumption of coal, but for the period mentioned it was seldom less than 7 lbs. per I.H.P. per hour. In a few cases horizontal engines were placed between the paddle-wheels, but these were objectionable on account of the weight they caused to be placed on the deck. To obviate this difficulty the steeple engine was designed by David Napier, and continued to be used for many years, especially in river steamers. It is now, however, seldom made, the direct acting

diagonal or the oscillating engine (which was first designed by Joseph Maudslay, in 1827), being generally employed for paddle steamers.

When the screw propeller was introduced, chiefly through the exertions of Mr. F. P. Smith and Bennet Woodcroft in this country and Captain Ericsson in America, the same kind of engines was used for driving it as was employed for paddle vessels, the connection between the crank and the propeller shafts being effected by means of gearing. The first British steamer of any size fitted with a screw propeller was the *Archimedes*, 237 tons, and built on the Thames in 1839. It was tested under Admiralty supervision, between Dover and Calais, with the fastest paddle-wheel mail packets on the station, and so satisfactory were the results that the Admiralty felt justified in introducing the screw propeller into the Royal Navy, and they led to the construction of the *Rattler*, which was launched from Sheerness Dockyard in April, 1843. The *Rattler* proving satisfactory, several other screw vessels were built for the Navy.

In the merchant service, also, the screw propeller made slow progress. The *Great Britain*, built in 1843, was the largest vessel of that day, and was remarkable not only for her size, but also because she was built of iron and was propelled by a screw instead of paddles. She was 322 ft. over all in length, 48·2 ft. in breadth, and 31·5 ft. in depth, with a gross tonnage of 3,270. She was built at Bristol from the designs of Brunel, her engines were made by J. Penn & Sons, Greenwich, her boilers by Fawcett, Preston & Co., Liverpool, and her engines were geared to the propeller shaft. The *Great Britain* made her first trip across to New York in fifteen days, and afterwards for many years was well known on the Australian trade. As screw propulsion became more common, gearing was gradually dispensed with, and the direct acting inverted or horizontal engines were used. These may be looked upon as the normal type of engines for the larger vessels employed in the merchant service and the Navy respectively.*

For a considerable time after the establishment of ocean steamship trade little attention was paid to the direct economy of fuel, although various causes, such as the improved form of the hulls, the use of iron in their construction, and the introduction of the screw propeller, led to a greater tonnage being propelled with the same amount of coal. There seemed to be a very general belief that high pressure steam was not only unnecessary, but was positively a disadvantage and a danger. Gradually, however, this opinion changed as the necessity arose for extending trade to foreign countries where coal could not be readily obtained, and the pressure of the steam was gradually increased, although in many cases this seems to have been brought about more in consequence of greater confidence in the materials of construction than from a distinct knowledge of the principles involved. Among those who led the way in the design and con-

* For details of the development of the marine engine in the British Navy, reference may be made to a series of articles in *The Engineer* for this year.

struction of engines of a more economical type the names of John Elder, Charles Randolph, and John M. Rowan deserve to be specially mentioned among Clyde engineers.

The first vessel fitted with compound engines by Randolph, Elder & Co. was the screw steamer *Brandon*. She made her trial trip in July, 1854, when her rate of consumption of coal was found to be about 3¼ lbs. per indicated horse-power per hour. The lowest rate of consumption of coal in steamers previous to that time was about 4 to 4½ lbs. per indicated horse-power per hour. Engines of a similar type had been made long before by Hornblower and Woolf, and had been used to a considerable extent on land, and occasionally in river steamers, but Randolph & Elder were the first to employ them for marine purposes. The second and third ships by this firm fitted with compound engines were the *Inca* and the *Valparaiso*, for the Pacific Steam Navigation Company. The engines of the *Inca* were started in May, 1856, those of the *Valparaiso* in July, 1856, and were designed according to the specification of Charles Randolph and John Elder, dated March 15, 1856. The pressure of steam used was 25 lbs. above the atmosphere. There were four cylinders: two high pressure of 50 in., and two low pressure of 90 in. diameter, all steam-jacketed at the top and bottom, but not round the sides. The cylinders were inclined to the vertical: the two high pressure opposite to each other, one on either side of the crank shaft, and both working on to one crank; while the two low-pressure cylinders were similarly arranged with regard to the other crank. The condenser was of the old-fashioned jet description, and was placed between the two sets of cylinders, underneath the crank shaft. On the trial trip, and during many years' subsequent service, the consumption of coal in these steamers was from 2½ to 3 lbs. per indicated horse-power per hour—a degree of economy never before realised in marine engines, amounting as it did to a saving of from 30 to 40 per cent. of the coal previously burned by steamers of the same class.

This success induced the Company to have their whole fleet fitted with engines of the same type, as to them the question of coal economy was of vital importance, owing to the great cost of sending coal to the Pacific stations. The next set of engines made for the Company was of exactly the same size, and was worked with the same pressure as the engines of the *Valparaiso*, but with the difference that they were steam-jacketed all over, instead of merely at the ends; and the result was that the indicated power rose from being under 900 to 1,150 horse-power—a result which shows the advantage of the steam jacket if used under proper conditions.

For a good many years, however, little progress was made by the compound engine, except with the Company which had introduced it. Some others had compound engines made by various makers, but bad design prevented them from being so successful as they ought to have been, and in a few cases they were taken out and replaced by single cylinder engines. Moreover, the engines of the Woolf type designed by Randolph and Elder were not fitted to give the highest efficiency, and it was not till the "receiver"

type of engine, with cranks at right-angles, was introduced by Nicholson, and brought prominently before the public by Mr. E. A. Cowper, that the compound marine engine became almost universal in the merchant service. Until about 1868 or 1870 the inverted direct acting two-cylinder simple engine held the place in the Mercantile Marine formerly occupied by the side lever engine. At these dates, however, the paddle-wheel had been almost entirely superseded by the screw in the propulsion of ocean-going steamers.

A few sentences of a theoretical nature may here be allowed. From the principles of thermodynamics we know that in any steam engine the heat converted into mechanical work is to the whole heat received as the range of temperature is to the absolute temperature at which the steam is received. We may increase the range either by raising the temperature at which the heat is received, or by lowering that at which it is rejected. Various attempts have been made with this latter object in view, but for all practical purposes we may consider the temperature of the condensing water as the lower limit. The lower limit being thus fixed, the only thing left is to increase the initial temperature either by directly superheating the steam or by increasing the pressure, and thus also raising the temperature. When steam of low pressure was employed in marine engines it was not unusual to superheat it to a considerable degree above the temperature corresponding to the saturated condition, but now that higher pressures have become common, superheating has been almost entirely abandoned, and further economy is now attempted chiefly by raising the pressure of the steam and improving the method of expansion. Experience shows that the economy of steam-engines does not necessarily increase with the increase of the pressure of the steam and the rate of expansion, and many have found that expansive working often means expensive working. When the pressure remains constant and expansion is augmented, at first there is a diminution in the consumption of steam, then it increases, and for each pressure there is a ratio of expansion which gives the maximum efficiency ; and it may be stated generally that in all classes of engines the efficiency depends not only on the *amount* but also on the *method* of the expansion.

In the single-cylinder engine, with even moderate steam pressure and expansion, a considerable amount of steam is condensed, not only on account of the mechanical work which is done, but chiefly through the action of the sides of the cylinder. During expansion, heat is restored to the condensed steam, and the film of water re-evaporates either partially or wholly. With low rates of expansion, the temperature of the internal surface of the cylinder is higher than the exhaust temperature ; while with high rates the temperature during expansion is so much reduced that when fresh steam enters at the beginning of the next stroke a large quantity is condensed. This is not all re-evaporated during expansion, and on the communication to the condenser being opened at the end of the stroke it is suddenly evaporated, and passes into the condenser with-

out doing useful work, a cause of loss of efficiency which increases with the pressure and ratio of expansion. Hence arose the necessity for compound engines.

Messrs. Randolph & Elder took up the receiver type of engine at an early period of its history, and from about 1868 a very rapid increase in the number of compound engines took place, so that in a very few years they became almost universal in the Mercantile Marine. A considerable improvement also took place in their efficiency. Steam pressures went up to 80 lbs., and in some cases to over 100 lbs., on the square inch; but it was soon found that at the higher pressures a recurrence of the evils of single engines took place.

This led to triple expansion engines, in which the steam is expanded successively in at least three separate cylinders, and such engines form the most important development in marine engineering which has taken place during the past few years. Generally speaking, steam of a boiler pressure of about 150 lbs. on the square inch is employed. Being admitted into the first, or high pressure, cylinder, it is cut off at about three-fourths of the stroke and allowed to expand; it then passes into the mean pressure, or middle, cylinder, and there expands as in the low pressure cylinder of an ordinary compound engine; and from that it passes into a third cylinder, of much greater capacity, where it is still further expanded; and, lastly, it escapes into the condenser. Such is the most common arrangement, but many triple expansion engines have four cylinders, the final expansion taking place in two cylinders simultaneously, instead of in one larger low pressure cylinder; and many other arrangements have been proposed, and in some cases carried out, but into the consideration of these we need not enter. The general principle is that in the triple expansion engine, the fall of temperature is divided between at least three cylinders, and the amount of condensation in each is reduced, and what does take place is to a large extent utilised during re-evaporation behind the pistons of the mean and low pressure cylinders. A saving of from 25 to 30 per cent. of fuel, as compared with ordinary compound engines, was the result of the introduction of those with triple expansion.

As the compound engine required to be compounded when pressures increased, so with pressures higher than those used in the triple expansion engine, quadruple or even higher expansion engines may become necessary. But it must be remembered that the rate of increase of temperature of saturated steam decreases as the pressure increases, and as the cost of construction of engines increases with the pressure, a point must soon be reached when the increase of efficiency of the steam will be balanced by the increase of cost, and by the loss of efficiency of the mechanism from increased friction; in other words, when the theoretical increase of efficiency will be balanced by practical losses. This point can only be determined by practical experience.

It will thus be seen that triple and quadruple expansion engines are the natural

developments of the ordinary compound engine, and as at present constructed have been evolved from the practice of many engineers, and I shall not attempt to apportion credit to all who have a claim to it. There are, however, a few names especially connected with the Clyde which will at once occur to everyone as deserving special recognition, and I think the first place will be unanimously given to Dr. A. C. Kirk, as the man who made triple expansion marine engines a commercial success. In 1874, when connected with the firm of John Elder & Co., he designed the engines of the *Propontis*. In these engines a pressure of 150 pounds on the square inch was employed. They had three cylinders of progressive capacities, and each was placed above its own crank in a three-throw crank shaft. The boiler employed was of the water tube type, and gave so much trouble that it was taken out and replaced by an ordinary internally-fired boiler carrying a pressure of 90 pounds on the square inch. The original engines of the *Propontis* are still at work. For some years after the above date little progress was made in the increase of steam pressure and the construction of triple expansion engines, the few that were made being of small size and the ordinary compound engine practically held the field till 1881, when Mr. Kirk, as senior partner of Messrs. Napier & Sons, designed and constructed the engines of the *Aberdeen* which he has described* before this Institution, and of which the following are the chief particulars. They are essentially of the same design as those of the *Propontis*, the cylinders being 30 in., 45 in., and 70 in., by 4 ft. 6 in. stroke. The boilers, two in number, are ordinary double-ended boilers, constructed entirely of steel, with six of Fox's corrugated furnaces in each, and the pressure is 125 pounds on the square inch. There is no superheater. The high-pressure cyclinder is not jacketed, the second is jacketed with steam of 50 pounds pressure, and the low pressure one with steam of 15 pounds above the atmosphere. When the ship was complete 2,000 tons of dead-weight were put on board, and the engines tested on a six hours' run at 1,800 horse-power, and the consumption of coal was found to be a little over 1¼ pounds per indicated horse-power.

The *Aberdeen* proving most successful gave a great impulse to the making of triple expansion engines, and the great majority of the engines of the larger sizes built for the merchant service during the last six or seven years have been of this type. It is not necessary that I should enter into particulars of these, as Mr. Parker's paper published in the last year's volume of the Transactions of this Institution will supply all the information which may be wanted, as no great change has taken place in the interval. A considerable number of triple expansion engines has been built for the British and foreign Navies. The largest set, of 13,000 indicated horse-power, built by R. Napier & Sons was for the Russian Navy. This and the further fact that the Società Hawthorn-Guppy, Naples, are constructing triple expansion engines for the Royal Italian twin-screw armour-clad *Sardegna*, of an aggregate power of 25,000 I.H.P.,

* Trans. Inst. N. A., vol. xxiii. p. 34.

the largest power hitherto put into any vessel, are matters for grave consideration by those who are responsible for our national defence.

With steam pressures above 150 lbs. on the square inch quadruple expansion engines have been designed. Mr. Walter Brock, of Messrs. Denny, Dumbarton, has taken the most prominent part in their introduction, and has displayed great ingenuity in their design. A form of quadruple expansion engines has recently been designed by Mr. Ferguson, of Fleming & Ferguson, Paisley, in which the cylinders are not arranged either all in line, or by twos in the same vertical plane, but are grouped together all at the same height above the crank shaft. The design seems very compact, but an opinion about the real value can only be given after we know something about the efficiency of the mechanism. Ordinary compound engines with two cylinders have been converted into triple and quadruple expansion engines in various ways, which have been discussed before this Institution.

The term "efficiency" should be understood in a much wider sense than that in which it is generally used, and should not simply be confined to the consideration of the consumption of fuel in a limited time, and to what may be largely an artificial measure of power. The shipowner should measure the efficiency of his ships by the ratio of the actual earnings in a given time, to that part of the capital which is chargeable to that time ; and this latter item includes not only share of first cost and daily expenses, but also of repairs and probable renewal, for an apparent economy may be bought too dearly. In this connection, and also in connection with the development of marine engines, it is only right to mention that Mr. Holt, an extensive shipowner, has stated that, in his opinion, mere economy of fuel is not much cared for now; coals, which used to be the greatest, are becoming one of the minor disbursements of a steamer; and he believes that the compound engine will come to be abandoned. He has, moreover, the courage of his opinions, and has built single crank engines of considerable size, which are said to give very good results. For large sizes, however, there are very obvious objections to such designs; and until more information has been given regarding their actual working, it is impossible to compare them with those which are more commonly used.

The use of the steam jacket both in land and marine engines has not always been accompanied by clear notions of its action on the part of engineers. It was originally designed by Watt ; and whatever he may have thought about it, mistaken ideas were held regarding it by his immediate successors, who, thinking that it only served to prevent radiation from the external surface of the cylinder, reasoning, as they did, from the caloric hypothesis, as the jacket presented a greater surface than the cylinder, inferred that it was not only unnecessary, but wasteful, and its use was to a large extent abandoned in land engines, and entirely in marine engines. It was reintroduced into the latter by John Elder, and with the design he used he was able to prevent a

considerable amount of condensation, and thus, as we have seen, improve the efficiency of the steam. But, contradictory as it may seem, the use of the steam jacket (as ordinarily constructed) is a violation of the fundamental law of maximum efficiency of heat engines, which requires that they should receive all their heat at the maximum, and give it out at the minimum temperature. In an engine with a steam jacket some of it is received at temperatures between these; and at times, when the heat imparted lessens the efficiency, as it evidently must do at and near the end of the stroke of a single engine, or of the low pressure cylinder of a compound engine. The steam jacket must thus be looked upon as a necessary evil, justified only by the physical properties of the steam, and of the materials hitherto used in the construction of engines; and unless the conditions under which the steam is used be carefully studied, and the jacket judiciously designed and carefully kept in order, it may be a cause of loss. For it can be shown that while the jacket increases the work done by the expanding steam, the increase is by no means so great as it would be if the heat employed in the jacket steam had been applied to generate more steam for use in the cylinder. Moreover, it is extremely doubtful if at sea steam jackets receive the attention they require to make them efficient. Hence, in multiple expansion engines, in which the variation of temperature is not very great, steam jackets have either been wholly or partially omitted.

The early forms of marine boilers were designed not so much with regard to strength as with the object of the greatest possible storage. They were simply large rectangular tanks with fire-places and flues, all with flat sides, and the opinion was expressed by some of the makers that "the most convenient form of boiler is that it should be adapted to the form of the boat, and that being taken for granted, the safety would depend on the strength of the metal and not upon the form." Watt had discouraged the use of high-pressure steam, and public prejudice had no doubt been raised against it by accounts of explosions in American river steamers which were much commented on in the British press. Several unfortunate explosions in this country of boilers of special design heightened the feeling, as the public were not in a position to distinguish what was due to faulty construction or careless working. The salting up of the boilers was another difficulty in the way of their development, but still the attempts of Messrs. Hall, of Dartford, in 1838, to get rid of it by means of surface condensation were not appreciated by engineers, and consequently the use of the surface condenser did not become general for many years after the above-mentioned date. As steam pressures rose to 20 or 30 lbs. on the square inch the boiler was strengthened by stays, and instead of flat flues, tubes were used to supply the necessary heating surface, and boilers of this type remained in use until the compound engine with surface condensation became common. Then, with pressures of from 60 to 90 lbs. on the square inch, it became necessary to use some form of cylindrical boiler, of which there is a considerable number of modifications. Those used in the Mercantile Marine

may be divided into two classes, (1) single-ended, or single-fired boilers, (2) double-ended or double-fired boilers, and such simple designs have been found preferable to the many special forms which have from time to time been proposed. The locomotive form of boiler is much used in steam launches of the Mercantile Marine, and in torpedo-boats and launches in the Navy, and in a few cases in larger ships. In all essential details the steam boiler is almost exactly the same as when compound engines became general except in the matter of strength, as we have now the command of improved materials and appliances. Steel is now almost exclusively used in the construction of their shells, and this in special forms, as for instance in Fox's corrugated furnaces, has enabled them to be safely worked up to pressures of 200 lbs. on the square inch. On the future of the marine engine Dr. Kirk has remarked, " that it is the boiler that bars immediate progress. The only part of the boiler that does bar immediate progress is the furnace, because as to the rest of the boiler, the boiler shell, the tubes, and the stays, we can get over all difficulties, but the furnace is the weakest part of the boiler, and anything further that can be done in the direction of a simple and strong furnace would be a very great benefit ; " but he further remarks in the same way as I have already pointed out, " that there must come a stop to this increase of pressure, not but that you will get economy as you go up in pressure, but at each step that economy will be smaller and smaller, while the cost of machinery will increase, and we have not only to look at the mechanical reasons, but we have also to look at the commercial ones." It is improbable for reasons connected with both the engines and boilers, that there will be any further great increase of steam pressure, unless there is a radical change in one or other, or possibly in both of these.

Theoretically, a pound of good fuel ought to evaporate 14 lbs. of water from and at the temperature of 212° Fah. In practice, only about 8 lbs. are evaporated, the remainder being wasted in imperfect combustion, in radiation, and above all in creating a draught. The efficiency is, therefore, only about ·6, so that there is still a wide margin for improvement.

Attention will therefore be given to every design which diminishes waste of energy. Amongst the most promising of these connected with the boilers is the introduction of forced draught to supersede, or to supplement, the natural draught produced by the funnel. This subject has been discussed before this Institution and is now receiving considerable attention from engineers, and it is to be hoped that sufficient data will soon be presented to the engineering public to enable a definite opinion to be formed regarding it. There can be little doubt, however, but that it is destined to have wide applications in the future.

The surface condenser came into general use at the same time as the compound engine, and no doubt contributed largely to its success. It has not altered much in

its design since that date, although recently in many cases its weight has been very much reduced. Time, however, will not allow us to enter into details of boilers, cylinders, and condensers, and of the various appliances connected with them. On these points reference must be made to the papers which have been read before this and similar Institutions.

The chief stages in the increase in the pressure of the steam used in marine engines and the consequent improvement in the efficiency have been already mentioned, but for convenience they may be recapitulated. Until about 1830 the pressure seldom exceeded three pounds on the square inch above that of the atmosphere. From that date a gradual increase took place, and in 1845 the average was about 10 lbs. on the square inch. By 1850 it had reached about 15 lbs. In 1856 Randolph and Elder employed pressures of 30 lbs. in their compound engines, but it was not till almost ten years later that such pressures became general in the merchant service. On the compound engine becoming common, pressures rose suddenly to 60 and in some cases 80 and 100 lbs. on the square inch, and since 1882 the average for triple expansion engines has been from 130 to 150 lbs., and for quadruple expansion engines 160 to 180 lbs.

The ordinary method of measuring the performance of a marine engine is by ascertaining the weight of fuel used per I.H.P. per hour. Watt, in his land engines, is said to have begun with 8·3 lbs. and to have gone down to 2·7.

The earliest marine engines must have used 9 or 10 lbs., and the well-known side-lever forms in use for so many years with a pressure of about 10 lbs. on the square inch are known to have consumed about 7 lbs. of coal per I.H.P. per hour. For engines in use immediately before the general introduction of the compound type 4 to 4½ lbs. was the average. Randolph & Elder, in their compound engines, had an average of from 2½ to 3 lbs. In 1872, when two cylinder compound engines had been in use for some years, it was found by Mr. Bramwell that the average of 19 ocean steamers was about 2·11, being a saving of nearly 50 per cent. on the ordinary engines; and in 1881 Mr. Marshall found the average of 30 steamers to be 1·828 lbs., or a further saving of 13·37 per cent., while with triple and quadruple expansion engines there has been a still further reduction of about 25 per cent., the consumption in some of those engines being as low as 1½ or 1¼ lb. of fuel per I.H.P. per hour.

The system of measuring the performance of engines in terms of the consumption of fuel per I.H.P. per hour cannot be considered at all scientific, although it may be convenient for approximate calculations. The quality of fuel varies considerably, and therefore it would be more exact to take instead, the number of units of heat imparted to the water in a given time. But for the pressures in ordinary use the problem of obtaining the greatest possible quantity of indicated work from a given

expenditure of heat in producing steam is so nearly identical with that of obtaining the greatest possible quantity of work from a given weight of steam, that in practice the difference between the two problems may be neglected. We ought, therefore, to use as unit of comparison the weight of steam consumed per unit of power given out. The best marine engines of the present day may be set down as consuming 12 lbs. of steam per I.H.P.

It must be admitted, moreover, that indicated horse power is not a very satisfactory measure of the efficiency of engines; not only on account of the difficulty of ascertaining its value, but because it is only one of the factors of the actual horse power. We might have two engines using the same amount of fuel or steam per I.H.P. per hour, but if the efficiency of the mechanism of the one was much greater than that of the other, the actual horse-powers of the two would be very different. The modern marine steam-engine is in such a stage of development that the comparison of ordinary compound with triple or quadruple expansion engines is apt to lead to wrong conclusions. We require in addition tests of the efficiency of the mechanism, and of this, it must be confessed, we know practically nothing. In the discussion on Mr. Parker's paper already alluded to, Mr. Seaton mentioned that in two ships alike in every respect except that the one had two-crank and the other three-crank engines, the result of their performances amounts to this: "That the consumption of coal per I.H.P. is precisely the same, but that the three-crank engine drives its ships half a knot or 5 per cent. faster than the two-crank engine;" and he goes on to say that "he thinks this a very important point, and one which has not been sufficiently dwelt on by marine engineers, because in discussing the relative merits of the two and three-crank engine, it has been practically limited to comparing the consumption of coal per I.H.P. Shipowners do not care so much about that as about the consumption of coal per ton carried, and the speed at which it is carried." Mr. Seaton has no doubt but that the three-crank engine is superior in every way to the two-crank one, whether it be a quadruple or a triple expansion, because, whether you have the quadruple engine, or the three cylinder triple, you have all the defects of the two-crank engine, an opinion which confirms what I have already said, and proves the necessity for attention being paid to the performances of the mechanism of marine engines. In every department of scientific investigation, progress has been marked by the advance in the methods of measuring the quantities involved. At first these are merely qualitative or relative, and the aim is always to make them quantitative and absolute. It seems to me that engineers have not devoted the attention which the subject deserves to the quantitative measurements connected with marine engines, the full consideration of which, however, is beyond the scope of this paper; and it is merely mentioned for the purpose of pointing out its importance.

Improved valve gears, pistons, bearings, both as regards design and arrangement,

the use of separate pumps for feed and circulating water, have all no doubt added to the efficiency of the mechanism of modern marine engines, although the multiplication and special arrangement of parts in some cases may have neutralised this improvement. Again, increased piston speed has led directly to economy of weight, the power developed being proportional to the speed of the piston, and the weight not being affected by the increased speed to any great extent. In the early marine engines from 150 to 200 ft. per minute were the average piston speeds; now from 600 to 800 ft. per minute are common, while speeds of upwards of 1,000 ft. per minute are not unknown. In order that high speeds may be safely and economically employed, it is necessary that the moving parts should be carefully balanced, the steam passages and ports carefully proportioned, the bearing surfaces ample, and that provision be made for a thorough system of lubrication.

The extended use of steel has been the means of reducing the weights of marine engines and boilers to a very considerable extent, and this is another part of the subject which has not received the attention it deserves, as the weight of the engines and boilers on board a ship has a considerable effect on its commercial efficiency, or the profits it yields to its owners. It is stated that every ton of deadweight capacity is worth on an average £10 per annum for freight; that is to say, that every 100 tons saved from the weight of the engines and boilers, without increasing the cost of working, is equivalent to £1,000 a year additional income to the owners. It is difficult to get exact figures showing the relation of weight of machinery, including engines, boilers, water, and all fittings ready for sea, in pounds per I.H.P., but the following* by Mr. Marshall, of Newcastle—who expresses the opinion that the weight of marine engines has not received the attention its importance demands—gives a near approximation:—

	Lbs. per I.H.P.
Merchant steamers	480
Royal Navy	360
Engines specially designed for light draught vessels	280
Modern locomotive	140
Torpedo vessels	60
Ordinary marine boilers, including water	196
Locomotive boilers, including water	60

No doubt these figures could be very much reduced if engineers endeavoured to make their designs as light as possible; but here again the commercial element limits their action, for light engines are always expensive, their high class workmanship and costly material more than balancing the advantages to be derived from reduced weight. In some of the ships which have been recently built for the Royal Navy, considerable reductions in weight have been made, but it is very doubtful if such designs would be found good investments if applied to merchant ships.

* Proceedings of the Institution of Mechanical Engineers, 1881, p. 461.

There is still another factor in the efficiency of marine engines which time will only allow me to mention, and that is the efficiency of the propeller, the conditions of which, notwithstanding all the ingenuity which has been spent upon them, still to a very large extent remain unknown. No subject has been more discussed before this and similar institutions, and yet Robert Griffiths, who had perhaps made more experiments, and worked more at the screw, than anyone else, in one of his latest utterances said that "four strips of plate iron set at an angle on the shaft which would hold the engine at the speed you required, would give you within half a knot of the best screw ever made." Mr. Barnaby, in his work on "Marine Propellers," although not prepared to endorse this statement altogether, thinks "it would be safe to say that a uniform pitch screw of the proper diameter and pitch, of the shape finally used in the *Archimedes*, will give within half a knot of the best screw ever made," so that progress in this department has been relatively small. Mr. Froude showed that only about one-half of the total power exerted by the engines is effective in propelling the vessel, the remainder being spent in overcoming friction and other resistances. In the actual construction of screw propellers considerable improvement has been made in the materials, for in addition to cast iron, steel and gun metal, as well as various other compositions, are used to a considerable extent, and quite recently various successful experiments have been made, about which the members of this Institution are soon likely to be informed.

In modern war-ships twin-screw propulsion is almost universal, and they can thus be manœuvred rapidly, and in the event of one propeller being injured in action or by accident, the vessel can be propelled, although at a somewhat reduced speed, by the remaining one, while in the event of injury to the rudder, it can be steered by means of the screws. The general adoption of twin-screw propulsion in the merchant service, at least in passenger steamers of the largest sizes, is likely to be one of the next steps in advance.

I have already spoken of the necessity of making our knowledge of the efficiency of the mechanism of marine engines more exact, by means of carefully conducted experiments. The same remark applies to our knowledge of the screw propeller. In determining the power necessary to drive a given vessel at a required speed, or predicting the speed with a given power, the engineer and shipbuilder must trust largely to their experience with similar ships and engines. Even when experiments are made with models this is largely the case. The efficiencies of the mechanism of the engines and of the propellers being practically unknown quantities, the required effective horse power is multiplied by a factor which includes both, in order that the gross indicated power may be obtained and the dimensions of the engines calculated—a somewhat empirical process, which shows the necessity for systematic experimental investigation before we can expect much improvement in efficiency.

The complete efficiency of a marine engine is the resultant of the separate efficiencies of the boiler, the steam, the mechanism, and the propeller. To give a rough idea of the value of this, the first of these components may be assumed at ·6, the second at ·2, and the third and fourth combined at ·5, so that the resultant efficiency is ·06 —that is to say, that only about one-sixteenth of the energy of the fuel is utilised in the propulsion of the vessel; so that, notwithstanding the progress which has been made during the first century of the marine engine, there is still a wide field for the ingenuity of the engineer and the shipbuilder.

As has been already remarked, what shipowners care about is the consumption of coal per ton carried, and the speed at which it is carried; and the following figures will be sufficient to indicate the progress which has been made since ocean navigation was firmly established.* The first steamers of the Cunard Company were under contract to go at a speed of 8½ knots; they indicated 740-horse power, and consumed 4·7 lbs. of coal per I.H.P. The speed and power were increased from time to time, and when the Americans put on the Collins Line, it was found necessary to build steamers which went 12 to 12½ knots, indicating 2,000-horse power, and consuming a fraction under 4 lbs. per I.H.P. These steamers made the passage, on an average, in 12 days 9 hours outwards, and 11 days 11 hours homewards; but as this was somewhat longer than the time taken by the American line, another step had to be taken in advance, and the *Persia*, an iron paddle steamer, was built in Glasgow in 1856. This vessel performed her voyage between Queenstown and New York, on an average, in 10½ days. She was fitted with side-lever engines indicating 3,600-horse power, and consuming 3·7 lbs. of coal per I.H.P. She attained an average speed of 12·9 knots, and consumed 150 tons of coal per day. The *Gallia*, belonging to the same Company, was built on the Clyde in 1879, and was fitted with compound engines indicating 5,000-horse power, and consuming only 97 tons of coal per day. She accomplished the passage in a little under 8 days, her average speed being about 15½ knots, and she carried, besides her passengers, fuel, stores, &c.—1,700 tons weight of cargo. Comparing this with the *Persia*, we find that this vessel burned 6·3 tons of coal for every ton of cargo she carried, while the *Gallia* burns something less than half a ton of coal for every ton of cargo she delivers, and, moreover, she carries it 2½ knots faster. In the *Arizona*, also built in 1879, the indicated horse power is 6,000, and she burns 5 cwt. of coal for every ton of cargo she carries, which she does at a speed of over 16 knots. Since 1879, many large steamers have been placed on the Liverpool and New York lines, and the passage is now accomplished in a little over 6 days, at a still further reduction of coal per ton of cargo carried.

The great economy in coal which has taken place during the last decade has made

* Chiefly from a lecture by Sir William Pearce, delivered during the Naval and Marine Engineering Exhibition at Glasgow, 1880-81.

it possible to steam from London to New Zealand without calling to replenish coal, and it was in such voyages that the triple expansion engine was first employed. As illustrating the economy of that type of engine, Mr. Parker has given* the following example:—"Two large passenger steamers of over 4,500 tons gross tonnage, having engines of about 6,000 I.H.P., built of the same dimensions, from the same lines, with similar propellers, are exactly alike in every respect except so far as their machinery is concerned. One vessel is fitted with triple expansion engines, working at a pressure of 145 lbs. per square inch, while the other vessel is fitted with ordinary compound engines, working at a pressure of 90 lbs. per square inch. Both vessels are engaged in the same trade, and steam at the same rate of speed, viz., 12 knots per hour. The latter vessel, on a round voyage of eighty-four days, burns 1,200 tons more coal than the former."

The subject of the resultant efficiency of steamships is beyond the scope of this paper, but still the following extract from a speech by Mr. Sutherland (Chairman of the P. & O. Company), at a meeting of the shareholders, will give some indication of the progress which has been made during the past ten years. He said: "It is a fact that during the last few years there has been a steady reduction in the expenditure of the Company in proportion to the amount of work performed. By way of illustrating what I say, I may mention that ten years ago, in 1877, I find that our expenses per mile navigated, including all normal and current charges, insurance and depreciation, were at the rate of 22s. 3d. per mile, whereas last year the same expenditure was at the rate of 18s. per mile only; but mark with this very great difference in the character of the work done, I may say, almost the same number of vessels as were employed ten years ago are employed now; but the tonnage of these vessels has been increased by between 50,000 and 60,000 tons, and therefore we have been working these larger vessels at that reduced rate of cost. Again, the increase in speed of our ships, as compared with ten years ago, has been between 16 and 20 per cent. Therefore, the mere difference of 4s. per mile conveys a very inadequate idea of the absolute reduction of expenditure in proportion to the extent and character of the work done." This latter fact is, of course, evident, for the figures given by Mr. Sutherland only include one of the variables of the problem. Cost per mile run is not sufficient to make an approximation to exactitude; we ought to know cost per mile per ton of freight carried per day. The subject of the efficiency of steamships from the owners' point of view is, however, a very large one, and time will not allow us to enter into it further at present.†

For the same reason we cannot enter into statistics showing the effect of the development of the marine engine on the progress of steam navigation. Moreover, the

* Transactions Inst. N. A., vol. xxviii. p. 129.

† On this subject a lecture was recently delivered by the author of this paper before the Clyde Steam and Sailing Shipowners' Associations, in which the various factors of the problem were discussed.

very complete returns of the Board of Trade, and such publications as Lord Brassey's "Naval Annual," give in a convenient form all the information which is likely to be wanted regarding the merchant service and British and foreign navies respectively, and its repetition is unnecessary.

I will only add further that this paper has been very hurriedly prepared at the request of the Council, and I trust that any important points which have been omitted will be given in the discussion.

DISCUSSION.

Mr. G. B. Rennie (Member): My Lord and gentlemen, this paper, which Professor Henry Dyer has been good enough to furnish for our instruction, is very interesting as far as it goes; but, with some diffidence, I would venture to suggest a few omissions which he has made, and one or two corrections which I think should be made before one can consider this as a complete history of the first century of the marine engine, a diffidence which is increased somewhat by the fact of his being Vice-President of the Institution of Engineers and Shipbuilders of Scotland, at whose invitation, I believe, we have come to Glasgow. As regards some of the earlier parts of the facts, I believe they are generally correct. On page 92 he mentions the name of Mr. F. P. Smith, and the introduction of the screw propeller. I regard this as being one of the most important epochs in the introduction of the steam-engine as suitable for steam propulsion. There is no doubt that Mr. Smith did exhibit a small launch in the river Thames—I think in the West India Docks—which was worked by a screw, but he was not the first who did that—there were several others before him. Mr. Smith had very considerable energy, and he asked Mr. Wright, the banker, to take the matter up as a very important subject in steam navigation. All the leading engineers were consulted, and they all gave an opinion adverse to it, with the exception, I may say, of my father, Mr. George Rennie, who made a report upon it to Mr. Wright, and stated that the adoption of the screw propeller would be a great improvement in steam navigation, and offered, provided he could get the money, to have a vessel built and design machinery suitable for the purpose, and a vessel was eventually built, called the *Archimedes*. The *Archimedes* was built on the Thames, and was engined by the firm in which my father took an interest. This was the first engine of any size at all used for steam navigation with the screw propeller. Those engines were of the vertical type, and the screw propellers were worked by gearing. The experiments made eventually led to the introduction of the screw propeller into the Navy and Mercantile Marine. My father and my uncle, Sir John Rennie, at that time knew Sir George Cockburn very well, and strongly recommended that the screw propeller should be introduced into the Navy. I may say at that time the officials were strongly against it. Sir George Cockburn, who was then senior Sea Lord, said, "If you recommend this as practicable, and recommend us what to do, we will see what can be done in the matter." Eventually it was agreed to purchase a small vessel—provided a speed of 12 miles an hour was obtained on trial—called the *Mermaid*, 130 ft. long and 16 ft. 6 in. beam. She was afterwards named the *Dwarf*. The *Dwarf* was the first screw vessel afloat in the Navy, and tried May, 1843. The *Rattler* was not tried till a year afterwards. She was adapted for the screw propeller, and the steam-engines were made by our firm, as well as the screw propeller on Mr. Rennie's patent, as well as the whole arrangements. A mean speed was obtained of 12½ miles. In the Mercantile Navy the first engines introduced with the screw propeller were those of the *Archimedes*, made by Messrs. Rennie, and the first screw propeller and engine which

was introduced into the Navy was in the *Mermaid*, or *Dwarf*, which was also designed and built by the same firm—those, I may say, were both geared engines. There is another little correction required on page 92. This is a subject which our firm had nothing to do with, but I know it is a fact. The *Great Britain*, it is said in the paper, was engined by Messrs. Penn & Sons. So it was, some years later, but not at first. Mr. Guppy made those engines, and they were among the first direct acting engines made. About the same time direct acting engines were introduced into the Navy by the requirements at that time of what were called block ships. These block ships were men-of-war for the protection of harbours; they were adapted for the screw propeller, and it was considered necessary that the machinery should be below the water-line. There were about six of these made, and the machinery was made by Messrs. Maudslay and by Messrs. Rennie, and I rather think by Robert Napier, but I am not quite certain. This may be considered the introduction of direct action engines for driving the propeller, which are now universally used for both war and mercantile ships. As regards the latter part, from 1854, I have really no remarks to make, and I leave other people to make criticisms thereon, but there are many other points which might be amplified and corrected. If this is to be considered as a history of the introduction of the steam-engine, I think that these few remarks which I have made should be recorded in the paper.

Mr. F. C. Marshall (Member of Council): My Lord and gentlemen, Professor Dyer in his interesting paper calls attention to several points in which I have personally taken some interest in the papers which it has been my privilege to read from time to time before this and other institutions. With reference to the weight of the engines constructed by my firm which Professor Dyer has specially alluded to, I may say, as to the question having still further development in the same direction, that the most recent engines now being constructed for Her Majesty's service are lighter by very much than any previously used. Unfortunately, I cannot give you the figures, but I shall have very great pleasure in forwarding them to Professor Dyer in order that he may insert them if he so desires. But as far as the power in relation to the weight of the marine engine is concerned it is being considerably increased, principally in the direction indicated by Professor Dyer—by the introduction of high-class material—by the running of engines at a very high speed of piston up to, in some cases over, one thousand feet per minute, and also by the application, which Professor Dyer has very properly mentioned, of forced draught to the boiler to even a further extent than has hitherto been adopted. There are two or three omissions of Professor Dyer's to which perhaps your Lordship and he will pardon my calling attention, because I think they are important as connected with the development of the marine engine. Professor Dyer has mentioned that certain circumstances have occurred and the engines have been made, but he has not given due prominence to the causes leading to that development. Perhaps you will pardon me just mentioning this. I think the introduction by Messrs. Randolph & Elder, or rather the development of the principle of surface condensation by that firm, has been a large factor in the development of the marine engine in all its more recent stages; but it would be hardly fair to give the whole credit of the introduction of surface condensation to Messrs. Randolph & Elder, because, as we are all aware, Mr. Samuel Hall, of Hull, was the first to introduce surface condensation into the marine engine, and his surface condenser only failed because he did not sufficiently provide for the contraction and expansion of the metal in the tubes. These failed, gave trouble, were condemned, and the adoption of surface condensation was thrown back several years. There is also another name should always be mentioned in connection with the introduction of surface condensation, that of Mr. John Frederick Spencer, an engineer, now of London, who is known to most of us, and who, at very great labour and expense to

himself, sought to bring about its general adoption, built and worked a vessel called the *Alert*, for the purpose of testing this principle, and he, if you remember, introduced the indiarubber packing at the end of the tube to get over the difficulties which Mr. Hall experienced. Messrs. Randolph introduced, I believe, circular tubes to get over the difficulty of expansion. Those were the primary stages. But for surface condensation we should not have had the present compound engine or the triple expansion engine. There is another element which has gone very far towards the development of the marine engine, and that is the introduction of Fox's flues. But for the introduction of the corrugated flue in the form which Mr. Fox adopted, or some others which have been recently adopted, we should never have attained to the use of the high pressures of which we are now availing ourselves. Another element is the introduction of steel in the place of iron. But for that we should never have been able to make boilers to bear the pressures at which we now work. I think that these factors ought to be noted in a paper of this nature.

Professor H. Dyer: I think I do notice them.

Mr. F. C. Marshall: I think that they should be more prominently noted as the factors which have led to the development of marine engineering, and therefore of naval architecture generally. Perhaps a little more might have been said for the other side of the island—I am not prepared to go fully into that, but I think some dates might be given which would show that the North-East Coast had a little to do with the development of the compound engine, and is not very, very far behind the Clyde. I think I myself, if you will pardon a personal allusion, made compound engines in the year 1863, which worked at 75 lbs. pressure, and I believe up to that time that was the highest pressure used in marine engines. With reference to the *Great Britain*, which has been alluded to here, I may say that that vessel was built by my predecessor in our Naples firm, Mr. Thomas Richard Guppy, who was in Bristol, but was obliged to leave that city on account of his health, and go to a more southern clime, where he established the present engineering business. The engines of that day were too costly in fuel to be very successful on the long Australian voyages, and were taken out. Had the projectors of that very handsome vessel known what we now know, she would probably have formed a member of the now magnificent fleets trading in the route of which she was the pioneer. With these remarks, my Lord, I beg to tender my thanks personally to Professor Dyer for having followed somewhat in the same line which I have been humbly following for some years.

Mr. F. J. Rowan (Visitor): My Lord, I desire merely to follow the previous speakers in offering one or two additions and corrections to Professor Dyer's paper. I wish to do so because, although he has been kind enough to allude, on page 93, to my father's name as deserving, amongst others, to be specially mentioned in connection with the improvement of the marine engine, yet he has spoken subsequently of that improvement in such a way as to make it difficult to understand why he made that allusion. Moreover, in the discussion of Mr. Parker's recent paper on a kindred subject, Mr. Scott, of Greenock, stated that a compound engine built in 1858 worked then with 125 lbs. pressure of steam, and that the efficiency attained by that engine had not been surpassed by any modern example; but in the report which I have seen of that discussion he did not mention the name of the builder of the engine, possibly from reasons of modesty, as he was associated with my father in the work, he having built the ship which contained that engine. I have placed on record in the Transactions of the Institution of Engineers and Shipbuilders in Scotland, for the year 1879, the evidence which entitles me to say that the modern compound marine engine using high pressure steam expansively, and with the surface condenser, was shown in practical operation in a screw steamer on the Clyde in the year 1858, by my father and those associated with him, before the modern compound engine, in

that form, for such a purpose was used by any other engineer in Great Britain. On page 93 of his paper, Professor Dyer has shown that Messrs. Randolph & Elder used compound engines with steam of 25 lbs. pressure with the old-fashioned jet condenser in 1856, and that that continued to be their practice up till 1860, at which time they began to use the surface condenser, their steam pressure being then under 40 lbs., and the consumption of coal in their steamers being from 2½ to 3 lbs. per I.H.P. The *Thetis*, which was the steamer containing the machinery alluded to by Mr. Scott, worked at 115 lbs. steam pressure in 1858, and was undoubtedly the first successful application of Hall's surface condenser to a compound engine in a steamer. Her consumption of coal was certified by Professor Rankine to be 1·018 lb. per I.H.P. on trials, and it was 1¾ lb. on regular trading work between Glasgow and Liverpool. Similar results were obtained with the engines and boilers of about twenty steamers built during the years up to 1866, the pressure of steam having been increased up to 120 lbs. in these examples, and several of them gave good results for over ten years, although some were destroyed by the then unknown forces of corrosion attacking both boilers and condensers. In the light of these results, I must say I am very much surprised that Professor Dyer should say, on page 93, that for a good many years after 1856, "little progress was made with the compound engine," and that other examples, besides those constructed by Randolph & Elder, were not so successful as they ought to have been, from bad design. The truth is that the results obtained in these early days have not yet been surpassed, and this proves either that the multiplication of cylinders is unnecessary, or, what is perhaps more likely, that a much higher efficiency was obtained from the boilers employed in those days than can be obtained from those now in use. Professor Rankine certified that the boilers of the *Thetis* evaporated 11 lbs. of water per lb. of coal, with ordinary chimney draught, the coal having a theoretical evaporative power of 15. That compares very favourably with the figures given by Professor Dyer on page 99. I must ask Professor Dyer to pardon me for making the complaint that on page 96 he gives the wrong impression that the boilers of the *Propontis*, which, as is well known, were of my father's patent, were taken out on account of their giving trouble in working. In the ordinary sense of the word, they did not give trouble in working. They had, unfortunately, an imperfect communication in the steam spaces, and that caused some fluctuation of the water level. There was no trouble in working them, even from this cause; but on one occasion, in consequence of the water level becoming too low in two chambers over the fires, these chambers were burnt, and burst at a pressure representing one-twentieth of the normal bursting pressure of that portion of the boiler. The boilers were taken out, as the owner himself admitted to me, simply because the owner (perhaps undervaluing the intelligence of Lloyd's surveyors) was afraid that, after the accident, the machinery of his steamer would not be classed. He has since frequently regretted having taken them out, and he found that he made a great mistake, because, as a fact, the surveyors would have been, from their better acquaintance with it, more ready to pass the machinery after the close examination of it which the inquiry into the accident entailed than before, and because the results he has since obtained with 90 lbs. steam have not been anything like so good as those with 150 lbs. in the first boilers. Professor Dyer has quoted Mr. Kirk's remarks in the discussion of Mr. Parker's paper, about the improvement of the marine boiler, but he has not given you Mr. Kirk's later deliverance on the same subject. In his recent address, as President of the Institution of Engineers and Shipbuilders here, Mr. Kirk spoke in another strain altogether about marine boiler improvement, and showed that in his opinion the water-tube form of boiler (the suitability of which for high pressures is, with all deference to Mr. Marshall, in no way dependent upon the presence of steel) is destined to come again to the front, and to be used again in producing such results as those to which I have referred.

Mr. J. Macfarlane Gray (Member of Council) : My Lord, I would ask permission, in connection with the early development of the marine compound engine, to mention the name of one who used to be well known in this district, and who is much respected by all of us who know him. I mean Mr. William Macnab, of Greenock, a man too unassuming ever to put himself forward. We owe to him the next important step taken after the work done by Mr. Rowan, father of the previous speaker. It has not been named that in the engines by Mr. Rowan there was only the one slide valve for the two cylinders, the high and the low. This necessitated great ingenuity in the design, and Mr. Macnab perceived that the development of the compound principle into a commercial practical engine was hindered by that ingenious compound slide valve. He therefore built an experimental steamer, the *Count Cavan*, with independent slide valves for the high and the low, and to work at higher pressures than had yet been attempted. He worked with steam at 90 lbs. pressure. The engine was a vertical one. The slide valve for the high-pressure cylinder was a piston valve, and for the low pressure he employed the common slide valve, just as is now done in the most modern engines. In the specification of his patent in September, 1860, he says : "The otherwise unoccupied space of this casing constitutes a kind of reservoir for the steam on its way from the high pressure to the low pressure cylinders." This is the first mention of the compound marine engine with intermediate receiver, and that step is one of the best ever taken in the development of the modern steam-engine. In this experimental engine there was one high-pressure cylinder, and two low pressure, as in many recent constructions. The name of the steamer was subsequently changed to the *City of Hankow*, and under that name it was sent to the East, and there purchased, in 1863, by the Mikado of Japan as a steam yacht. Having talked over these experiments with Mr. Macnab while he had them in hand, we went over the old ground again in conversation a few weeks ago in London, where Mr. Macnab is now a neighbour of mine. Those here who knew him on the Clyde will understand how agreeable it is to me to mention his name to you.

Mr. G.W. Manuel (Member) : My Lord, I should like to make a few remarks upon this most interesting paper, illustrating the remarkable progress which has taken place in the marine engine during the last century, and I think I may be able to add a little information which Professor Dyer wishes us to give. It so happens that last year was the jubilee year of the P. & O. Company. Fifty years ago, in 1837, a steamer was built for that Company called the *Iberia*. I will give you the figures as nearly as possible. These papers are put in our hands just at the beginning of the meeting, and, to enable us to give you the data correctly, it would have been better if we could have had these papers a little earlier ; but still, for all practical purposes, I will give you these data, to show the remarkable progress which has taken place during the last fifty years in the marine engine. This vessel was 220 ft. by 30 ft., and drew 10 ft. to 12 ft. of water. Her I.H.P. was 400, her steam pressure 7 lbs., her speed 7 knots, and her displacement about 400 tons, and her consumption of coal was 21 tons per day. Last year the *Victoria*, our jubilee steamer, was built. Her dimensions were 560 ft. by 52, her draught of water was 23 ft. 6 in. I mention the draught of water because I think she can be judged of better when you know the displacement, the body of water which they have to impel with a certain amount of fuel at a certain speed. The draught of this vessel is 23 ft. 6 in., as I said before, and her I.H.P. is 7,000 ; her pressure of steam is 150 lbs., against 7 lbs. ; and the speed 16 knots per hour, against 7. The displacement is 10,000 tons, and the consumption at 16 knots is 100 tons. Reducing that to something like practical data, the results are as follow :—One ton of coal in the *Iberia* propelled 19 tons of displacement at the rate of 168 knots per day. In the case of the *Victoria*, one ton of coal propels 100 tons of displacement at the rate of 384 knots per day. This shows a remarkable progress in fifty years. Now, we have had the names of those gentlemen given us to-day

who have been associated with this remarkable progress during the last fifty years. Some of those names I happen to have been associated with. I was the first apprentice under Mr. John Elder when he was introducing the compound engine, and therefore I watched the progress of marine engineering very closely. Then we have had another gentleman's name mentioned to-day, which is the next step, and that is Mr. Kirk. We are very much indebted to that gentleman, as we all know, for the next stage of advancement. Following him, there is Mr. Brock, to whom we are indebted for the next stage of advancement. But for all that, we must not forget that these results which have been given us to-day are owing, not only to the marine engineer, but very greatly also to the skill of the naval architect, because the form of the vessel is a very great factor in the results that have been attained; but in order to keep and to hold the position which we have to-day, we must not forget that we cannot be disassociated from the naval architect, and that his knowledge and skill have gone very far to produce the results which have been brought before you. How far this progress is to go on during the next fifty years I cannot tell, but at the same time we are in a very different position to-day to what we were one hundred or fifty years ago. Other nations, on the Continent and elsewhere, were not engaged to the extent they are now in producing the marine engine in steamers, and I think if there is any lesson to be learnt from that it is this, that we must be more on our guard than ever. When there is peace perhaps one may slumber, but now it is a time of war with us all; and, looking at the competition that there is, it behoves every one of us to be up and doing, and to endeavour to keep the name which this country has got above all nations in the world. There is no other nation or place which should get the credit, or which has got the credit, of this advancement, but—I was going to say Scotland—but Great Britain and Ireland. I think we should all be satisfied with the part played by England and Scotland, but we have a power in Ireland at present that is engaged in the manufacture of engines and ships which must be referred to in mentioning any great achievements in naval construction, and also of engines of late years, and we must not leave them out. Gentlemen, I thank you very much for listening to the observations I have made.

Mr. George Roger (Visitor): My Lord, I have only a word to say. This is distinctly an historical paper, and, with regard to the history of the steam-engine, I am unfortunately old enough to remember history; but what I would mention is that a great many of the leading spirits are forgotten. When I went to King's College in 1840, two steamers were lying dismantled opposite Somerset House, the *Aurora* and the *Echo*. Those steamers were engined by a Swede. They were paddlewheel engines, compound engines, working at right angles to her bottom. Mr. Gray will no doubt remember them when I say they were broken up in about 1840. There is one other little historical remark. Whenever the triangular connecting rod happens to come up either in England or elsewhere, there are many claimants for the honour of it. I happened to call on Mr. F. P. Smith in relation to the *Archimedes* in 1832, and he then showed me the design of an engine designed for him by Mr. Galloway, and it was the most ingenious arrangement I ever saw, but though I turned it round for hours I could not understand it. It was an arrangement by which one crank, say one foot long, turned two cranks six inches long. I think that should be recorded.

Mr. H. A. Salvesen (Member): My Lord and gentlemen, I should just like to say a few words with reference to this being the centenary of steam navigation. Professor Dyer said in his opening remarks that he thought Mr. Symington had received too little attention. That is the opinion generally in the east country from which I come, and especially at Grangemouth, where the first practical steamer was built. I do not wish to enter into the relative merits of Mr. Miller, Mr. Taylor, and Mr. Symington, for it seems perfectly plain to me and to everyone at Grangemouth and that

locality that Mr. Symington was the man who deserved the greatest credit. If he did not, and it belonged to either Mr. Miller or Mr. Taylor, why was it that neither of these gentlemen followed up the experiments performed on Dalswinton Loch in order to bring their ideas to perfection. This was done by Mr. Symington when he produced the *Charlotte Dundas*, which was quite a practical little steamer, and was the first one with the connecting-rod coupled direct to the crank on the paddle-shaft. I would just bring these facts under your notice, as there has been a movement started in Grangemouth for the purpose of celebrating this centenary in some tangible sort of form, and it would be a matter of very great satisfaction if you, my Lord, or some of the gentlemen who are members of the Institution of Naval Architects, would give us assistance in that direction. We have as yet not decided what form the memorial is to take. It might even take the form of an experimental tank at the Glasgow University, as suggested by Mr. Martell. Anything which would keep in mind the name of the man to whom we really owe the great progress which has been effected during the last 100 years I think would be satisfactory, and we are not particular as to the locality in which the memorial is placed, so long as something is done by which he may be remembered.

Professor Henry Dyer (Member): My Lord, I think there is nothing in the discussion which calls specially for observation, because the remarks which have been made have been chiefly supplementary and not critical. I hope they will all appear, and will supplement this paper. The only complaint made in the discussion is that with regard to the remarks about water-tube boilers. I was not in this country when the *Propontis* was built. Of course, my authority is altogether second-hand, but I find the opinion I express here is recorded in the Transactions of this Institution (Vol. xxiii. p. 34), and, therefore, I must refer to Mr. Kirk for that opinion. I should be sorry indeed to do Mr. Rowan's father any injustice, because I think he was one of the leaders of this matter on the Clyde. With regard to the omissions which have been mentioned, I explained when I commenced my paper that it was intended for the purpose of promoting discussion, and was not to be considered as complete in itself. I must say that I am very much gratified with the discussion that has taken place, and I would ask the Council to consider whether they should not invite a few more of the members to communicate their views for the purpose of making the discussion more complete. I thank you very much for your kind attention.

The President: I am sure, gentlemen, you will wish me to thank Professor Dyer for his valuable paper. As he explained to you at first it is an historical paper, and he invited remarks to supply omissions. I am very glad indeed that the learned Professor is satisfied with the discussion which has taken place. There is one word which I must say. The learned Professor asked that the Council should correspond with gentlemen who have not spoken or written on the subject. That is entirely contrary to our practice, and would lead to an amount of printing, the end of which we should never see. We cannot depart from that practice, which has universally prevailed with regard to papers and the discussions upon them.

STEAM TRIALS OF THE R. ITALIAN IRONCLAD "LEPANTO."

By Major Nabor Soliani, Royal Italian Navy; Member.

[Read at the Thirtieth Session of the Institution of Naval Architects, July 26th, 1888; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The R. Italian ironclad *Lepanto* underwent recently a series of trials at sea which are interesting, both in themselves and with reference to the size and type of the ship and the power and type of her engines and boilers. It is, in fact, the first time that a power of 16,000 I.H.P. has been developed on board an ironclad, giving her a speed of over 18 knots, and that a large number of locomotive boilers, in connection also with boilers of a different kind, have been worked together with complete success.

I have got permission from His Excellency the Minister of Marine, Mr. B. Brin, the designer of the ship, to put before this Institution the results obtained, hoping that their record, enhanced in importance by the considerable amount of attention that this type of ship has attracted from the naval and the engineering world, will be a useful addition to the knowledge already gained on the propulsion of modern war-ships.

A description of the *Italia*, the sister ship of the *Lepanto*, was given some time ago in scientific newspapers (*Engineering*, February 17, 1888, page 158), and therefore I shall restrict myself here to the principal dimensions and data of the *Lepanto* that have a bearing on the subject.

The principal dimensions of the *Lepanto* are as follows:—

Length between perpendiculars	400 ft. 6 in.
Breadth	72 ft. 9 in.
Depth, moulded...	46 ft.
Mean draught, normal	28 ft. 4 in.
Area of midship section	1,843 sq. ft.
Displacement	13,851 tons.

The ship is entirely built of steel, and has no sheathing on her bottom, differing in this respect from the *Italia*, in which the steel bottom is sheathed with wood and zinc.

The internal divisions are pretty much the same in both ships, with the exception of the boiler-rooms, which are differently arranged on account of the different type of the boilers.

The *Italia* is fitted with twenty-six boilers of the Admiralty oval marine type, divided into six compartments, three forward the engine-rooms and three aft, each compartment having its own funnel.

On the *Lepanto* there are also six compartments of boilers, similarly situated, as shown on Fig. 1 (Plate VI.), but only the two near the engine-rooms have marine oval boilers, four in each, and the remaining four compartments have locomotive boilers, four in each, making a total number of eight oval marine boilers and sixteen locomotive boilers. Their arrangement is clearly shown on the sketch.

The locomotive boilers, which form, perhaps, the main interesting feature of the machinery, deserve special notice. There are two furnaces in each boiler, separated by a longitudinal water space, which, however, stops short of the tube-plate, leaving a passage between, above the bridge. The furnaces are just as long as the fire-grate, but to prevent the fire damaging the tubes, and to ensure a good combustion of the gases, a high hanging inclined baffle brick bridge is fitted, as usual in railway practice, in each furnace at the end of the fire-grate.

The bottoms of the ash-pits form water-pans to keep the grates cool; the latter are made with longitudinal cast-iron rocking bars.

The oval boilers have three furnaces, each discharging into one common combustion chamber. Their grates have ordinary fire-bars $\frac{3}{4}$ in. thick, with $\frac{5}{8}$ in. interstices. There are four funnels—two for the forward set of boilers, and two for the after one.

In each set the oval and the locomotive boilers have each their own separate funnel.

The boiler rooms are provided with twenty fans—four in each oval boiler room, and three in each locomotive room—capable of maintaining an air pressure of over $2\frac{1}{2}$ in. of water in the former, and of 4 in. in the latter.

The main engines, four in number and arranged in four separate compartments at the centre of the ship, are of the well-known type of Messrs. Penn, with three equal vertical cylinders, as applied on H.M. ships *Ajax* and *Agamemnon*, working compound at moderate power, and direct at full power.

The cylinders are steam jacketed, and fitted with a double ported flat-slide valve, having an expansion valve working on its back, which allows of any degree of cut-off being fairly obtained.

The main engines work their own air and main feed pumps, the circulating pumps only being, as usual, moved by independent engines.

The following are the leading particulars of the engines and boilers :—

PARTICULARS OF MACHINERY.

Oval Boilers.

Boilers—	
Number of boilers	8
Height	14 ft. 7 in.
Width	11 ft. 7 in.
Length	10 ft. 2 in.
Furnaces and combustion chambers—	
Number of furnaces in one boiler	3
Diameter of furnaces	3 ft. 2 in.
Length of furnaces	7 ft. 4 in.
Width of combustion chamber	10 ft. 2 in.
Depth ,, ,,	2 ft. 2 in.
Height ,, ,,	6 ft. 6 in.
Capacity of furnaces and combustion chambers in one boiler above fire-grates	240 cubic ft.
Grates—	
Length of grates	6 ft. 6 in.
Area of grates in one boiler	59 ft. 8 in.
Arrangement of fire-bars	Longitudinal.
Type ,, ,,	Ordinary.
Material ,, ,,	Iron.
Thickness ,, ,,	$\frac{3}{4}$ in.
Interval between ,,	$\frac{5}{8}$ in.
Tubes—	
Number of tubes in one boiler	306
Material	Brass.
Length of tubes between tube plates	7 ft. 3 in.
Diameter of tubes { Internal	$2\frac{3}{4}$ in.
Diameter of tubes { External	3 in.
Area through tubes in one boiler	12·6 sq. ft.
Heating surface in one boiler { Tubes	1,744 sq. ft.
Heating surface in one boiler { Total	1,920 sq. ft.
Total for all eight oval boilers—	
Grate area	478·4 sq. ft.
Heating surface { Tubes	13,952 sq. ft.
Heating surface { Total	15,360 sq. ft.
Area through tubes	100·8 sq. ft.
Water surface	862 sq. ft.
Capacity of furnaces and combustion chambers above fire-grates	1,920 cubic ft.
Capacity of steam chamber	2,560 cubic ft.
Weight of water	124 tons.

Funnels—	
Number of funnels	2
Size (oval)	5 ft. 6 in. × 7 ft. 4 in.
Height above fire-grate	76 ft.
Area	80·6 sq. ft.
Ratio of—	
Cube heating surface / grate area	27
Total heating surface / grate area	32·1
Area through tubes / grate area	0·211
Area of funnels / grate area	0·168
Water surface / grate area	1·8
Capacity of steam chamber / grate area	5·35
Capacity of furnace and combustion chambers / grate area	4
Load on safety valves	60 lbs.
Fans—	
Number of fans	8
Diameter of fans { four	4 ft. 6 in.
Diameter of fans { four	6 ft.
Type of engines	Brotherhood

Locomotive Boilers.

Boilers—	
Number of boilers	16
Height „ „	9 ft. 6 in.
Width „ „ in front	7 ft. 11 in.
Length „ „	14 ft. 5 in.
Diameter of barrel	6 ft. 7 in.
Furnaces—	
Number of furnaces in one boiler	2
Width „ „	3 ft. 3 in.
Length „ „	6 ft. 8 in.
Height of crown above fire grate	6 ft.
Capacity of furnaces in one boiler	260 cubic ft.
Grates—	
Length of grates	6 ft. 6 in.
Grate area in one boiler	42·2 sq. ft.
Arrangement of fire-bars	Longitudinal rocking.
Material	Cast iron.
Type	Having side inclined combed air grooves.

Tubes—	
Number of tubes in one boiler	376
Material	Brass.
Length of tubes between tube plates	7 ft. 7 in.
Diameter of tubes { internal	1¾ in.
Diameter of tubes { external	2 in.
Area through tubes in one boiler	6·27 sq. ft.
Heating surface in one boiler { tubes	1,490
Heating surface in one boiler { total	1,670
Total for all sixteen locomotive boilers—	
Grate area	675·2 sq. ft.
Heating surface { tubes	23,840 sq. ft.
Heating surface { total	26,720 sq. ft.
Area through tubes	100·3 sq. ft.
Water surface	1,412 sq. ft.
Capacity of furnaces and combustion chambers above fire grates	4,160 cubic ft.
Capacity of steam chamber	3,360 cubic ft.
Weight of water	105·6 tons.
Funnels—	
Number of funnels	2
Size (oval)	6 ft. 4 in. × 8 ft. 2 in.
Height above fire grate	72 ft.
Area	94 sq. ft.
Ratio of—	
$\frac{\text{Cube heating surface}}{\text{grate area}}$	35·3
$\frac{\text{Total heating surface}}{\text{grate area}}$	39·6
$\frac{\text{Area through tubes}}{\text{grate area}}$	0·15
$\frac{\text{Area of funnels}}{\text{grate area}}$	0·14
$\frac{\text{Water surface}}{\text{grate area}}$	2·09
Ratio of—	
$\frac{\text{Capacity of steam chambers}}{\text{grate area}}$	4·98
$\frac{\text{Capacity of furnaces and combustion chambers}}{\text{grate area}}$	6·16
Load on safety valves	60 lbs.
Fans—	
Number of fans	12
Diameter „ { four	4 ft. 6 in.
Diameter „ { eight	6 ft.
Type of engines	Brotherhood.

Engines.

Description of engines	Three equal vertical cylinders, Penn's type
Main Engines—	
Number of engines	4
Number of cylinders in one engine	3
Diameter of cylinders	54 in.
Stroke	39 in.
Number of cranks in one engine	3
Angle of cranks	120°
Collective indicated horse-power	18,000
Revolutions	96
Condensers—	
Number of condensers	8
Collective cooling surface	31,300 sq. ft.
Propellers—	
Number of propellers	2
Description	Admiralty.
Diameter	20 ft. 6 in.
Number of blades	3
Pitch	20 ft. 6 in.
Pitch ratio	1
Surface of blades in one propeller	80 sq. ft.

Particulars of Trials.

The trials were to be made in accordance with the following programme, proposed by Messrs. John Penn and Sons, and accepted by the Ministry of Marine:—

1. A trial with only two oval boilers at work, and the after engines only at work on the compound system, to ascertain the most economical steaming of the ship.

2. A trial with the eight oval boilers at work, the four engines working compound.

3. Ditto, with the four engines working direct expansion.

4. A forced draught trial with only the after set of engines and boilers at work, the engines working direct.

5. A forced draught trial with all eight oval boilers and eight locomotive boilers at work, the four engines working direct.

6. A full-power forced draught trial or trials, with all the engines and boilers at work, the engines working direct.

This programme was not completely carried out, on account of the ship having been put in commission, which prevented the final 18,000 I.H.P. trial being made. It went, however, far enough to show what can be expected from the engines when working at their full power.

The trials were made along the eastern coast of the Gulf of Genoa, from Spezia to Genoa and back, the two runs being altogether over eighty nautical miles. A portion of the forward run from Spezia to Genoa was taken in each trial, to bring up the engines to the desired speed.

The speed of the ship was ascertained by means of bearings on well-known points on shore in both runs.

The bottom of the ship was fairly clean, the ship having been docked on March 1, viz., about one month before the trials.

The ship was fully laden in all the trials, with very slight differences of draught.

The indicated horse-power developed was ascertained from the indicator cards of the main engines, without taking any account of the steam used for auxiliary purposes.

The trials were carried out under the direction of Mr. J. W. Fairley and Mr. May, who represented the firm, and of Mr. Holland, the engineer in charge.

All the results obtained and the conditions of trials are figured on the annexed table, and to them the following remarks will serve as an illustration.

One of these remarks is of great importance, as it refers to the behaviour of the locomotive boilers, which was perfect.

After the rather discouraging experience with locomotive boilers working in sets on board some ships, as the *Flavio Gioja* of the Royal Italian Navy, and the *Polyphemus* of the Royal English Navy, some fear was entertained that similar troubles might be experienced with the *Lepanto*, in which the difficulty appeared to be still greater, considering the larger number of boilers to be worked together in so many different separate compartments.

But nothing of the kind happened, nay, everything went to prove the contrary.

From the very beginning of the preliminary trials, which took place towards the end of last year, the locomotive boilers gave evidence of their good working, which went on increasing trial after trial, so as to be now an established fact.

They never primed nor gave any trouble whatever. The feeding was occasionally uncertain, but the fault was due to air that collected in the main feed pipe. This imperfection was removed, and on the last two trials the feeding was quite satisfactory. After each one of the last three forced draught trials the locomotive boilers had tubes leaking, but in small numbers, and not more, comparatively, than the oval boilers, which, even in this respect, did not behave better. Moreover, there were discrepancies between the different compartments of boilers, locomotive as well as oval, which show that the management of the fires has a good deal to do in this matter.

The ventilation of the locomotive stokehold is excellent. The fans being fitted on top of the boilers, no current of air strikes the floor, and a thorough cool ventilation and forced draught are obtained without any inconvenience whatever from coal dust. The same may be said of the oval boiler stokeholds, where the fans are fitted on the wings behind the boilers, but, although the supply of air is ample, the temperature does not during forced draught fall so low, probably on account of the boilers facing each other. The mean temperature of the oval boiler stokeholds was about 106° against 88° in the locomotive boiler stokeholds, while the atmospheric temperature oscillated about 58°.

The engines worked very satisfactorily all through the trials, without the slightest hitch occurring in any part of the whole machinery. This circumstance helped, no doubt to some extent, the good performance of the boilers, which had never to be checked or hampered when in full swing.

The power of 16,150 I.H.P. on the last trial was developed by the engines with a mean air pressure of 1·9 in. of water in the locomotive boiler stokehold, and of 1·6 in. in the oval boiler stokehold, the coal burnt per square foot of grate per hour being 51 lbs. in the former and 38 in the latter. But as, at the preliminary partial trials mentioned above, the oval boilers were worked up to $2\frac{1}{2}$ in. of pressure and the locomotive boilers up to $3\frac{1}{2}$ in. with perfect success, burning 45 and 68 lbs. of coal respectively per square foot of grate per hour, there is evidently room left for more power. The gain in speed which would follow such increase of power is, however, not very great, as is clearly apparent from the results of the last two trials, and still more from the I.H.P. Curve, shown on Fig. 2 (Plate VII.), of which something will be said hereafter.

A very good performance was that obtained on the sixth trial (April 28), when, with only two-thirds of the boilers at work, the engines developed over 12,000 I.H.P. (two-thirds of the total power), driving the ship at nearly 17 knots. The cut-off being at 0·175 of the stroke, the steam worked with a ratio of expansion 4·35, which, from the consumption of water shown by the indicator cards, appears to give the most efficient performance of the engines at great power.

A circumstance deserving notice is that all these trials were carried out with the ship's stokers, who for the greater part were not yet trained for forced draught stoking.

Regarding the efficiency of the engines, although the consumption of coal was the lowest on the first trial, when the two after engines were acting compound at very low power with a great ratio of expansion (about 11), this condition of working does not appear to be the most efficient, as the consumption of water shown by the indicator cards was greater on this trial than on the next, when the ratio of expansion was reduced to 3·5 only.

The same thing happens, although in a less marked degree, when the engines act with direct expansion, as there is no material difference in the consumption of steam over four expansions. Below this ratio the consumption increases, as may be seen from the results of the last two trials.

To have more complete data of the ship and engines' performance, besides the trials above mentioned, runs were made on the measured mile to ascertain the speed of the ship corresponding to the lowest possible speed and power of the engines; also the power and speed of the engines for a speed of about 10 knots of the ship.

The results are as follows:—

Speed of ship ... ... knots	2·7	10
Revolutions	15	55
I.H.P.	158·6	2403

Now I beg to call attention to Fig. 2, (Plate VII.,) in which the results relating to the ship's performance are graphically recorded, in connection with the E.H.P. curve, as was determined by experiments on the model of the *Italia* made for the Royal Italian Government by Mr. R. E. Froude at Torquay, by the kind permission of the Admiralty.

The E.H.P. curve *a a* corresponds to a displacement of 14,784 tons, which is approximately the mean displacement of the *Lepanto* at the various trials. The *Lepanto* being a finer ship than the *Italia* for the same displacement, the ordinates of curve *a a* should be lowered a little, but, considering that the bottom of the *Lepanto* was not perfectly clean, curve *a a* may be accepted as sufficiently correct.

b b is the I.H.P. curve.

d d is the "Indicated thrust curve," as it results from the I.H.P. curve. The dotted line at the bottom of curve *d d* is to show the increase of thrust due to the friction of the forward set of engines when they were acting at low powers with the after set.

According to this curve the initial friction of the engine would be about 7·5 per cent. of the load at full power.

f f is the "curve of the net resistance of the ship" as it results from the E.H.P. curve.

It will be noticed that the undulation characteristic of the E.H.P. curve *a a* and of the net resistance curve *f f* at about 16·5 knots, is faithfully reproduced on the I.H.P. curve *b b*, and on the indicated thrust curve *d d*, giving strong evidence of the correctness and importance of the method of investigation devised by the late Mr. Froude.

Curve *c c* gives the ratio $\frac{\text{F.H.P.}}{\text{I.H.P.}} = p$, viz., the propulsive co-efficient or the "net total efficiency of propulsion," which slightly increases at the higher speeds when it approaches to the standard value 0·50.

Curves *m m* and *n n* give the "co-efficient of performance" for displacement and midship section.

Curve *g g* gives the ratio between the net resistance of the ship and the indicated thrust.

Curve *h h* gives a similar ratio when the initial friction of the engines is taken off from the indicated thrust.

All these co-efficient curves *c c*, *m m*, *n n*, *g g*, *h h*, show more or less an undulation at about the same speed at which there is a marked change on the curve of E.H.P.

Curve *r r* in Fig. 3, (Plate VII.,) gives the I.H.P. in function of revolutions.

By following the method of investigation devised by Mr. R. E. Froude, and illustrated in his paper "On the Determination of Dimensions for Screw Propellers," read at the Institution of Naval Architects, 1886, I have approximately determined for the maximum speed of 18·38 knots the efficiency of the *Lepanto's* screw propellers, which would have an abscissa-value, 10·75, very close to maximum efficiency. This abscissa-value and the corresponding net total efficiency of propulsion are plotted on Fig. 4, (Plate VI.,) which is the reproduction of Mr. Froude's standard curve for the efficiency of screw propellers, as illustrated in his paper above mentioned.

With this abscissa-value the true slip of the *Lepanto's* screw propellers at the speed of 18·38 knots would be about 20 per cent., while the apparent slip is only $2\frac{1}{2}$ per cent., leaving 17·28 per cent. for the speed of the wake that follows the ship.

	Trials.							
	1 April 4.	2 April 7.	3 April 11.	4 April 14.	5 April 28.	6 April 28.	7 May 5.	8 May 12.
Sea	Calm.	Calm.	Rather rough.	Calm.	Heavy cross.	Calm.	Rather rough.	Calm.
Wind	Light N.O.	Light N.O.	Fresh N.O.	Light N.O.	Light S.W.	Light N.	Fresh N.	Light N.
Mean draught.. ft.	30′ 4″	30′ 4″	30′ 3″	30′ 3″	30′ 1½″	30′ ½″	30′ 3″	30′ 4″
Area of midship section sq. ft.	1,999	1,999	1,993	1,993	1,984	1,978	1,993	1,999
Displacement .. .. tons	14,860	14,860	14,810	14,810	14,740	14,690	14,810	14,860
Wetted surface .. sq. ft.	36,500	36,500	36,430	36,430	36,325	36,255	36,430	36,500
Mean speed of ship .. knots	7·25	13·7	13·3	14·4	15·89	16·78	18·18	18·38
Indicated horse power ..	1,004	6,230	5,714	7,385	10,330	12,010	15,260	16,150
Number of boilers used ..	2 Oval	8 Oval	8 Oval	4 Oval 8 Locom.	8 Oval 8 Locom.	8 Oval 8 Locom.	8 Oval 16 Locom.	8 Oval 16 Locom.
Number of engines used ..	2	4	4	2	4	4	4	4
Mode of action of engines ..	Compound	Compound	Direct	Direct	Direct	Direct	Direct	Direct
Area of fire-grate used, sq. ft.	94·1	478·4	478·4	Oval 239·2 Locom. 337·6	Oval 478·4 Locom. 337·6	Oval 478·4 Locom. 337·6	Oval 478·4 Locom. 675·2	Oval 478·4 Locom. 675·2
Heating surface used — Tubes	3,488	13,952	13,952	18,896	25,872	25,872	37,792	37,792
Heating surface used — Total	3,840	15,360	15,360	21,040	28,720	28,720	42,080	42,080
Mean steam pressure in lbs. per sq. in. — Oval boilers	50	54	37	52	48	51	53·5	54·2
Mean steam pressure in lbs. per sq. in. — Locom. ,,	..	..	..	58	52	56	58·5	60·
Mean steam pressure in lbs. per sq. in. — Engine room	48	51	34	47	44	47	49	49
Mean air pressure in ins. of water — Oval boiler stokeholes	Natural	0″·65	0″·94	1″·	1″·	1″·5	1″·	1″·6
Mean air pressure in ins. of water — Locom. boiler stokeholes	..	..	..	1″·9	1″·2	2·5	2″·	1″·9
Cut off — In H.P. cylinders	0·1	0·5	0·1	0·45	0·175	0·175	0·3	0·3
Cut off — In L.P. ,,	0·6	0·6	..	..	..	..	..	..
Ratio of expansion	11·1	3·5	5·56	1·89	3·93	3·93	2·63	2·63
Mean pressure in lbs. per sq. in. — H.P. cylinders	15·3	23	15·4	36·62	23·5	26·1	30·65	31·9
Mean pressure in lbs. per sq. in. — L.P. cylinders	6·8	13	..	..	..	..	..	..
Mean vacuum in condensers ins.	28·6	28·7	28·6	27·	27·5	27·5	27	27
Revolutions per minute ..	38·8	70·53	68·73	74·25	80·95	85	92·05	93·5
Apparent mean slip per cent.	6·4	4·25	4·6	3·8	2·7	1·8	2·34	2·72
Mean speed of piston per minute .. .. ft.	252·2	458·25	445·25	484·27	526·5	552·5	598	607·75
I.H.P. per sq. ft. of grate ..	10·7	13	11·9	12·8	12·6	14·6	13·1	14
Heating surface per I.H.P. in sq. ft. — Tubes	3·48	2·24	2·45	2·55	2·5	2·17	2·46	2·34
Heating surface per I.H.P. in sq. ft. — Total	3·82	2·47	2·69	2·84	2·78	2·41	2·74	2·61
Coal used per hour, in tons ..	0·9	6·4	6·9	11·4	13·7	16·8	21·8	23·5
Coal used per I.H.P. per hour, in lbs.	2·02	2·27	2·75	3·45	2·97	3·14	3·2	3·3
Coal burnt per sq. ft. of grate per hour — Oval boiler lbs.	21·3	29·9	32·3	34	35	38	33	38
Coal burnt per sq. ft. of grate per hour — Locom. ,,	..	..	..	51	41	58	49	51
Steam used per I.H.P. per hour as shown by indicator cards	16·1	15	18·2	22·2	18·4	18·2	21·1	20·7

FIG. 5.

AVERAGE CARDS TAKEN DURING THE TRIALS.

Scale $\frac{1}{24}$.

Date of Trial .....April 28

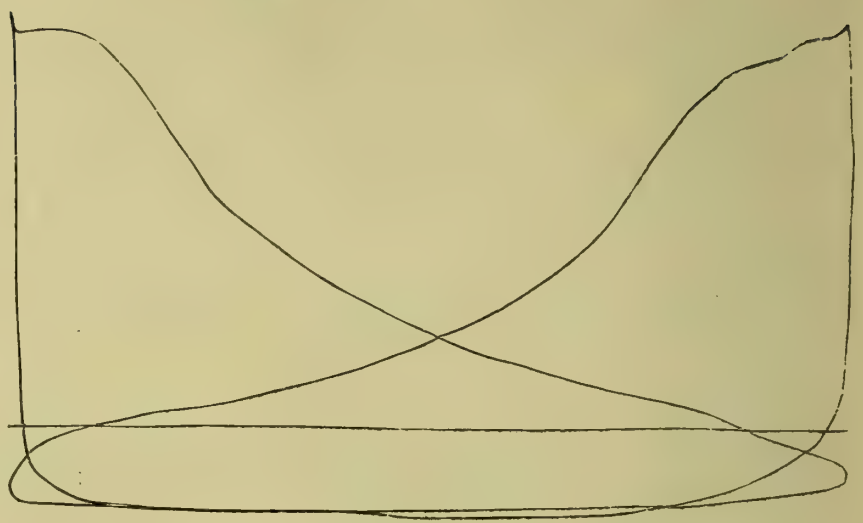
Mean steam pressure in engine-room ..... } 49 lbs.

Mean vacuum ..... 27·8 in.

Cut-off ..... 0·175

Revolutions per minute 85

Indicated horse power 1,032



Date of Trial .....May 5

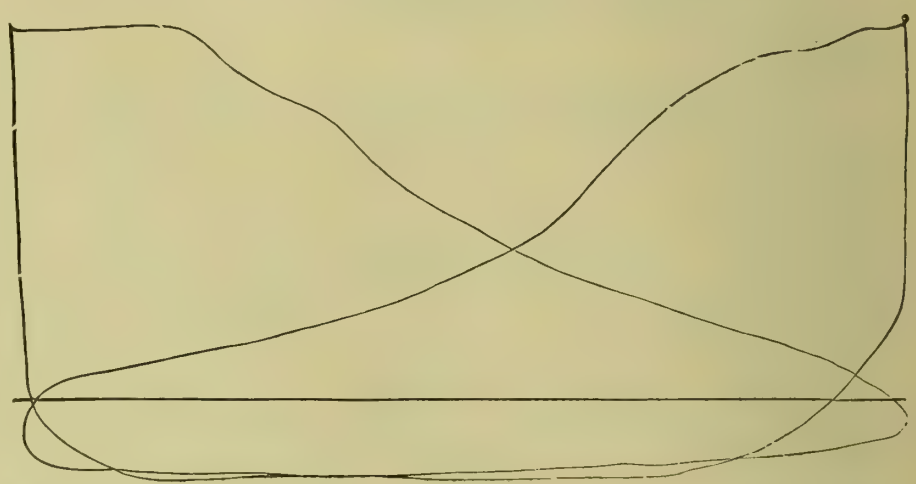
Mean steam pressure in engine-room ..... } 49 lbs.

Mean vacuum ..... 27 in.

Cut-off ..... 0·3

Revolutions per minute 92

Indicated horse power 1,305



Date of Trial.....May 12

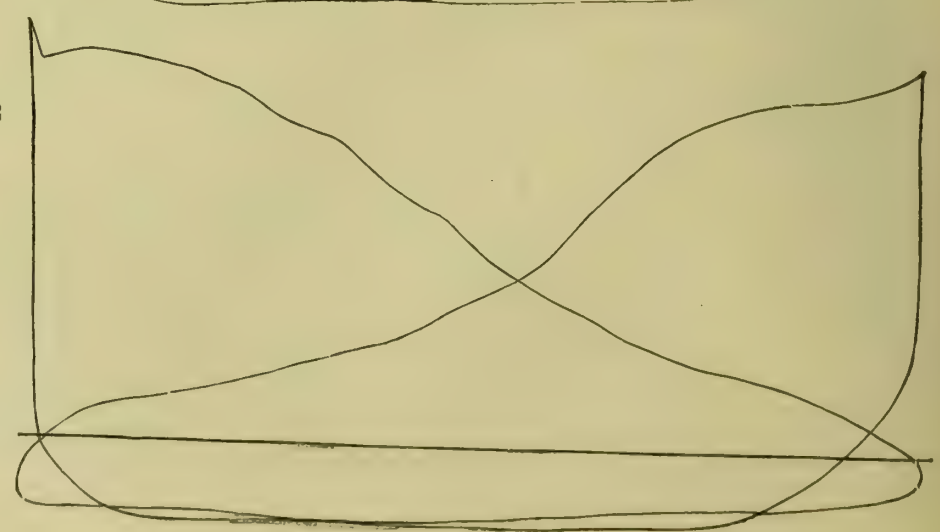
Mean steam pressure in engine-room ..... } 50 lbs.

Mean vacuum ..... 26·7 in.

Cut-off ..... 0·3

Revolutions per minute 93·5

Indicated horse power 1,358



APPENDIX.

To comply with the wish expressed by Mr. F. C. Marshall in his remarks, I have given in Fig. 5, mean specimens of the *Lepanto's* indicator cards taken during the last three trials.

Regarding the performance of the *Flavio Gioja's* locomotive boilers, which was not so satisfactory as in the case of the *Lepanto*, it is necessary to bear in mind that the boilers worked under very different conditions in the two ships, especially on account of the different type of the engines. The *Flavio Gioja* having trunk engines, the cylinder condensation of steam was much larger than in the *Lepanto*, with the consequence that the boilers of the *Flavio Gioja* had to be overworked to give out the required power. This fact goes far enough to account for the difference in the results of the two ships, but some collateral circumstances came also into play, as for instance the less roomy and less comfortable condition of the *Flavio Gioja's* stokeholes, which prevented the boilers being so regularly and properly worked as in the *Lepanto*.

On the official trials, the engines of *Flavio Gioja* developed a mean of 4,156 I.H.P., at the rate of 14·35 I.H.P. per square foot of grate, with a consumption of seven tons of coal per hour, viz., at the rate of 55 lbs. of coal per square foot of grate; the cut-off in the cylinders being 0·35, corresponding to a ratio of expansion 2·33. The consumption of steam as shown by the indicator card was about 23 lbs. per I.H.P. per hour, viz., 10 per cent. larger than that of the *Lepanto* for the same output of power per square foot of grate.

DISCUSSION.

Admiral Sir John Hay, K.C.B., D.C.L., F.R.S. (Vice-President): My Lord, I am sure that the meeting will recognise the thanks that are due to the gallant and eminent officer of the Italian Navy who has submitted this information to us. I am sure that our thanks are still more due, and I daresay that he will convey them, to the Minister of Marine, who has given his authority and permission to give the Institution this information. I do not for a moment propose to criticise the paper, or to offer any remarks, because they can come with much greater effect from other members of the Institution; but it is not two years ago since I had the advantage of receiving the greatest possible civility from the officers of the Italian Navy, and of visiting the *Lepanto*, being at Spezia, under the kind conduct of my friend Admiral Labrano, with the permission and assistance of Baron William Acton, who was then in charge of the Admiralty, and Admiral Bracchia at Rome, and Admiral Albini; and at Naples, at Santa Lucia, of seeing over the works of the Italian Navy there, with the assistance of Admiral Ferdinand Acton. Therefore I thought, having received myself so much courtesy and kindness from the officers of the Italian Navy, and having been witness of those magnificent structures which have been created under the control of the Minister of Marine himself, that the meeting would think it would fall gratefully from me if I expressed to the gallant officer the sympathy which we have with the great strides that the Italian Navy has made in her war-ships, and also express the kindness and courtesy which the officers of this country always receive from the officers of the Italian Navy. I have nothing to add further than this; but I trust the gallant officer will convey to M. Brin the thanks of this Institution for the courtesy shown in permitting this paper to be read, and to the gallant officer for the admirable manner in which he has performed the task.

Mr. F. C. Marshall (Member of Council): My Lord, I rise with very great pleasure and satisfaction to compliment my friend, Major Soliani, on the very admirable paper which he has done us the honour of laying before us to-day. There has been a large amount of anxiety in the Italian

Navy, as to the probable performance of the machinery of the *Lepanto*, more especially with regard to the locomotive boilers with which that vessel is fitted. Many of us know from personal experience the great difficulty there is in getting a large number of stokers to work together in separate stokeholds, and especially in a climate such as that of the country to which the gallant officer belongs. It is a very great satisfaction, I think, to find that Major Soliani and the contractors, Messrs. Penn, have succeeded so admirably in producing the great results here recorded, under such very difficult circumstances with regard to the locomotive boilers of the *Lepanto*. It will be within the recollection of the meeting that I have on more than one occasion taken the liberty of illustrating those boilers, and comparing them with some others, rather to their detriment. I take this opportunity at once of, in some measure, qualifying the remarks I may have made on previous occasions. It is quite clear that when they are not overworked they do well. It is possible that, if they were placed in the same position as those of the *Flavio Gioja* and *Savoia*, and others of similar type, to which I have previously alluded, and were expected to do as much work as the boilers in those vessels are called on to do, or as in the case of the *Polyphemus*, some of the same difficulties might be experienced; but I sincerely congratulate Major Soliani on the results which he has attained under the conditions stated. I only hope that in the future these boilers will prove equally satisfactory as they have done in their first trials. I do not know that I can say anything further with regard to the paper. There is a great deal in it that one needs to think about and study, and to commence talking about it after merely seeing the paper for a few minutes would be presumptuous, inasmuch as it could not be discussed in a manner at all worthy of the paper, or of the distinguished officer himself. But, my Lord, there is one thing which I venture to suggest would enhance the value of the paper very much, if Major Soliani would kindly do it, and that is to add to the paper the indicator diagrams taken in the trials. These would very much enhance its value for the purposes of the Institution and its members. The data would be much more complete and satisfactory if that were done. If Major Soliani would kindly give us also the indicator diagrams taken from those vessels with which he compares the boilers, the *Flavio Gioja* and *Savoia*, it would further enrich the paper. I have personally very great pleasure in thanking Major Soliani for his valuable contribution.

Mr. W. H. White, F.R.S. (Vice-President): I take it that the absence of discussion is the greatest compliment which can be paid to this paper, because (as Mr. Marshall has well said) it contains a mass of information, put in the ablest way, most thoroughly analysed according to the most advanced methods which the profession knows, and which can only be dealt with by close and careful study. What Sir John Hay has said with regard to the kindness and courtesy experienced by Englishmen at the hands of the officers of the Italian Navy, and what we all owe to Major Soliani and to his Excellency Signor Brin, is well known. It is a very great pleasure to us to think that these gentlemen, besides holding such distinguished offices as they do in the Italian Navy, are members of this Institution. The Italian Minister of Marine has been for a long time a member of this Institution, and in giving his consent to the publication of this paper he no doubt was influenced by the fact that this Institution has in some measure been a help to the progress of naval science in Italy as well as in this country. I only speak the feelings of all the members of this Institution when I say that the International character it possesses is a feature which we highly value. We have the honour of numbering amongst our membership, not merely the most distinguished naval architects of all the great war navies of the world, but we also have the honour of including in our list the most distinguished private shipbuilders of all countries. I think that fact is one on which we may congratulate ourselves, and I hope that feature will always be maintained in this Institution. The data which Major Soliani has put before us are most valuable. But he well recognises the fact that

engine designing has gone beyond the stage represented by the arrangements of the machinery in the *Lepanto*. The Italian Navy is now constructing other large ships of which I hope we shall obtain the particulars and trials from Major Soliani at a later date, and in which the latest developments of marine engineering find their place. Therefore this paper marks progress as well as furnishes us with information, and it is only fair to the Italian Naval authorities and to the makers of the machinery, Messrs. Penn, that we should recollect that the machinery of the *Lepanto* was designed ten or twelve years ago, and therefore, in considering the results recorded for consumption of coal and weight of machinery in relation to power, it is not fair to take this as a test of what is being done in the Italian Navy at this time. The paper really deals with the last stages of a great piece of work, extending over a long period, and during the progress of which there have been enormous advances both in shipbuilding and marine engineering. Still it contains many features of permanent value, and information not previously attainable. The association of the locomotive type of boiler with the ordinary type is a cheap way of getting the portion of the power required in a war-ship to attain her highest speed, and the plan has attracted our attention in England, as well as the attention of designers in Italy, for many years. In fact, the plan would have been carried out in some of H.M. ships had it not been for our painful experience with the locomotive boilers which were first fitted in the *Polyphemus*. One circumstance must be noted as regards the locomotive boilers in the *Lepanto*, in which they are exceptional. I believe the pressure of steam in them was under 60 lbs.; whereas in most recent applications of the locomotive or modified locomotive type of boiler in war-ships, the pressures have been twice to thrice as great. What applies to the *Lepanto's* performances, therefore, may not necessarily hold good when we are dealing with an equally numerous group of locomotive boilers worked at higher pressures. However that may be, we have here for the first time an example of the complete success of the working together of a great number of locomotive boilers, and that is a very valuable result to attain. The performance of the ship as an instance of economical propulsion is proved most excellent by the facts recorded in the diagrams. Whether we consider the ratio of speed to I.H.P., or the enormous range of speed over which the engines are capable of working, the performances of this ship are truly remarkable. If gentlemen who are more particularly interested in the Mercantile Marine will just consider what the difference is in our practice in war-ships as compared with that to which they are accustomed, and having to pass, as is done by the *Lepanto*, from something like 2,000 up to 18,000 I.H.P., they will recognise a few of the difficulties which the designer of the machinery for war-ships has to face. The *Lepanto* in her ordinary cruising is perhaps making eight or ten knots an hour, when accompanying a fleet. She is then indicating roughly say 10 per cent. of her full power; then, when the time for special effort comes, she rushes up to 18,000 I.H.P. and a speed of 18½ knots. The condition of course is altogether different from that which prevails in a mercantile ship, like one of the great Atlantic or Australian mail steamers, whose mission it is to cover fixed distances at the highest speed attainable. I put it to the meeting, as it is so well illustrated in this paper, that the enormous range of power over which the engines of war-ships have to work is a point that should be considered in the criticism of the design of war-ships' machinery, as compared with the design of merchant ships. I would again tender my thanks to my good friend, Major Soliani. We have been for many years intimate friends, and I do not like, therefore, to say all I feel about him, but I am sure that the Institution, apart from any personal circumstance of that nature, will join me in thanking him for what he has done to-day in giving us this paper.

Major N. Soliani (Member): My Lord President and gentlemen, I have to thank Admiral Sir John Hay, and my friends Mr. F. C. Marshall and Mr. W. H. White, very much, for what they

have said with regard to me, and for the benevolent manner in which they have discussed the paper. I should like to say that my object in coming here was not so much to give information as to obtain knowledge, and to have the pleasure of being more intimately associated with a learned society like this. In going home it will be a very pleasant task of mine to convey to his Excellency the Minister of Marine the kind feeling you have expressed towards him, the Italian Navy, and the Italian officers, which feeling, it is very gratifying to say, has always existed between the Italian and the English Navies. As you know, a good deal of the material of our ships, engines, guns, machinery, and so on, was made and is being made in this country; moreover, a great part of our knowledge in naval matters we have got from you, so that we are very much indebted to England and Great Britain in this respect. And I do only wish that, should evil times come, the Italian Navy may be on the side of the English. I say so because Admiral Sir John Hay, in speaking yesterday of your want of ships, put the Italian Navy on the wrong side. Mr. Marshall asked me to give the particulars of the *Flavio Gioja's* performance, and the diagrams of the *Lepanto's* steam trials. I am very glad to be able to give both in an appendix to this paper. As to Mr. White's reference to the *Re Umberto*, I should be only too glad to come back next year again and review the results of the trials of this ship. I thank you all very much for the very indulgent reception which you have accorded to my paper.

The President: Gentlemen, I think it is hardly necessary that I should ask your kind permission to convey our united thanks to that distinguished gentleman who has just addressed us. I have very few observations to make, but I think when I sit down you will say they are not altogether out of place. I congratulate our distinguished friend upon two points: first of all, the excellence of his paper, which is so excellent that it is practically, as our friend has said with great tact, unanswerable —it requires a little more study before any remarks could be addressed to it with any effect. That is no slight triumph, but I must congratulate him also on the extreme delicacy and grace with which he has addressed us all in a foreign tongue. If any of us, even our most eminent members, were to go to Italy, I think, probably, they would think not twice, but a good many times, before they started on such an adventure as that. Now, gentlemen, I think it is not at all an inappropriate occasion to mention that which many of you are not aware of, that no less than 15 per cent. of our members are of different nationality to ourselves. Major Soliani is a very old member of this Institution, and, I think you will all admit with me, has shown the highest possible qualifications and capabilities as a Naval Architect, and as such, a member of our Institute; but, gentlemen, I also wish to point out the extraordinary value to an Institution such as ours, of our intimate, close, and friendly association with the most eminent men in their different lines in the great studies of naval architecture and marine engineering almost all over the world. The value of their association consists in the means afforded to us and to them of interchange of ideas, giving us the results of their experiments and the results of their trials, so that we are able to compare them with our own. It is almost of inestimable value for such an association as ours to have those relations with eminent men such as they are all over the world. Now I will remind you, I see before me a very distinguished and honoured friend of mine, Admiral Likhatchoff, one of the most regular attendants at our meetings on all occasions. There are one or two faces as familiar as those of any other members of the Institution to me. There is Monsieur de Bussy, holding the highest position in the French Admiralty; there is Monsieur Berrier Fontaine, a personal friend of many of us, holding again the highest position in one of the great dockyards of France, at Toulon. I may mention also, that we have Major Soliani holding that very high position which has been described to you in the Italian Navy. We have Signor Mattei, a distinguished countryman of Major Soliani, one of our Honorary members. When I come to our

Honorary associates I find no less a name than that of H.I.H. the Grand Duke Constantine of Russia, I find his Grace the Duke of Palmella of Lisbon another of our Honorary associates ; so that, gentlemen, these are circumstances of great congratulation to ourselves, and I think it is well from time to time that our Institution should be reminded of the distinguished names which are included among our members and associates. We have to-day elected a very distinguished Japanese gentleman as a member of the Institution. We have distinguished Germans, Austrians, Spaniards, eminent citizens of the United States of America, we have Brazilians ; we have one Turkish member at least, that I know of, and if I were to go through the list, which my memory hardly supplies me with, I could prove my words, that we have members of this Institution all over the civilised world, and, gentlemen, I need hardly point out the advantage of such intimate relationship as that which exists between all our members, and all builders and users of ships. They give us the benefit of their information, and we compare notes in the most friendly manner, and to the eminent advantage, I hope, of all those countries as well as our own in that interchange of ideas. I have thought it right—I am sure you will pardon me—to make this slight reference to these distinguished names, and I cordially thank on your behalf, in which thanks I most sincerely join, my distinguished friend Major Soliani for the valuable contribution that he has given to our Transactions to-day.

ON THE POSSIBLE EFFECT OF HIGH EXPLOSIVES ON FUTURE DESIGNS FOR WAR-SHIPS.

By Captain C. Penrose FitzGerald, R.N., Associate.

[Read at the Thirtieth Session of the Institution of Naval Architects, July 26th, 1888; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The data which I have been able to collect with reference to my subject are so extremely meagre, that I feel almost ashamed to bring it before this Institution in its present stage; and my only excuse for doing so is the great interest and importance which attaches to it, and the urgency, if I may so express it, of the subject of high explosives used in shell fired from regular powder guns, not pneumatic tubes. I am also in hopes that some of our naval architects may have been prying into the future by watching experiments and collecting information, and that they perhaps may be able to throw more light upon the subject than I can do, and that the discussion which I hope will take place, will at any rate cause us to realise that we are face to face with a new method of attack, which may very possibly call for some modifications in ship designs for war purposes.

In spite of the cloud of secrecy which our neighbours have endeavoured to cast about the subject, we have been aware for some time back that they have been making experiments with a high explosive called melenite, a species of blasting gelatine, which, I am informed, is poured liquid into the shell, and then allowed to solidify.

The explosive force of melenite is about equal to gun-cotton, weight for weight, but volume for volume it is much greater; that is to say, melenite is heavier, so that in a given space, say the interior of a shell, you can put half as much again of melenite as gun-cotton.

The difficulty of using high explosives in shell has hitherto been the liability of the concussion of the gun causing the shell to burst in the bore, and thus to destroy the gun.

How this difficulty has been overcome, I am not in a position to tell you; but that it has been overcome in the case of melenite we are very well assured, as numerous experiments have been carried out with it.

As to the much more sudden and destructive effect of what are called the high explosives, as compared with gunpowder, you are, no doubt, all aware. An ordinary gunpowder shell fitted with a percussion fuze, when it struck the thin side of a ship which it was capable of penetrating, passed several feet onwards before it exploded; but shells fitted with high explosives are said to burst actually on contact, or when the shell is passing through the thin side, so that the destruction caused is out of all proportion to the gunpowder shell, many square yards of the side being actually blown away, or, as it was graphically described to me, nothing left but daylight. On the other hand, it is somewhat cheering to hear that there is an antidote, and that very moderate armour is capable of breaking up these high explosive shell, and rendering them comparatively harmless. Thus it is stated that steel armour four inches thick is capable of breaking up the melenite shell from the French 16-centimetre gun—a gun about equal in power to our 6-in. gun. If this is really the case there is something hopeful in the prospect for this country, as it points to an important future for our numerous so-called obsolete thin-armoured ships. They are iron-built, and although they lack many of the best features of modern ships, such as numerous compartments, double screws, under-water steering gear, &c., they would seem to be worth re-engining and re-arming, not with two or three heavy guns, but with numerous light, quick-firing ones, firing high explosives. They would, I believe, prove formidable fighting machines against any partially armoured ships.

It is stated that the new French cruiser, *Dupuy-de-Lome*, of 4,000 tons, and a speed of nineteen knots, is to be plated with 4-in. steel armour, for the purpose of breaking up high explosive shell, though she appears in Lloyd's "War-Ships of the World" as only a "deck-protected" cruiser. It is also stated that the French are plating their coffer-dams with a similar object. This would be internal armour with a vengeance. But I only give you the report on hearsay evidence. Very possibly some of you may have better information, and if so, I hope you will give it to us.

One thing is quite certain, and that is, that our neighbours across the Channel are worth watching. Somehow or another, they generally manage to take the lead of us in other matters besides the cut of a dress, or the trimming of a bonnet. I say it without an idea of reproach to our own countrymen. The French are a quicker-witted and more imaginative race, blessed with a subtler genius, whilst we perhaps may pride ourselves on greater solidity and firmness. At any rate, we cannot change our national characteristics; and I am not sure that it is altogether a disadvantage to allow others to go ahead and try experiments for us, provided we watch closely, and do not allow ourselves to get too far astern; but this latter is an important proviso.

The French had the first steam three-decker, the first ironclad, and they were years ahead of us in heavy breech-loading guns. During the last war we were not too proud to copy the models of their sailing ships, which were universally acknowledged to be superior to our own ; and I am not quite sure that if we had adopted the same course in the present day we should not have a more powerful and trustworthy Navy than we have at present, though this, of course, is a matter of opinion, as the ships have not yet been tried in battle.

I am not in favour of slavishly copying the French, or any other nation, but I say that they are worth watching.

It seems to me that we are working round in a circle in this question of guns and armour ; and the introduction of quick-firing guns of 6-in. calibre, and the very probable introduction of high explosives in shell, will, I think, necessitate a return to moderate armour, and lighter armaments altogether ; with, possibly, the abandonment of very heavy guns afloat, as not being worth their weight and trouble, when the slowness of their fire is taken into consideration.

The almost complete sacrifice of a ship of 10,000 tons to the carrying of two or three heavy guns seems to be a miscalculation of the chances of hitting from a moving platform : for gunners, after all, even behind armour, are only human beings, and liable to make mistakes ; and it seems likely that the introduction of high explosives in shell of moderate calibre will help to bring us back again to some modification of the type of our earlier ironclads, so as to insure us against the greater number of chances ; for we must ever bear in mind that it is simply a question of chances. There is no absolute safety, nor anything approaching to it, in any design of war-ship ; and the recent practice of reducing greatly the extent of armour, for the purpose of thickening it in places, has exposed large areas as happy hunting grounds for high explosive shell of small calibre, Almost all modern ships have many such places which they cannot afford to see destroyed with impunity.

I should like to know, for instance, how those huge Italian ships, with hardly any armour (ships which some of our naval architects so greatly admire), will get on when their sides in the region of their water-lines are attacked with high explosive shell, and large areas of them blown away. I should imagine that they would get a heavy list, if indeed, the righting lever does not disappear altogether, and I cannot see that the weight of armour expended in their submerged deck will be of much value to them.

It will be seen that my remarks are merely intended to be suggestive. I have made no attempt to dogmatise on the subject of high explosives. The question is in an untried and speculative stage, and my only object is to draw attention to it, and to urge our

naval architects to watch closely the experiments which are about to take place with the *Resistance* in this connection; and I sincerely hope that there will be no hollow pretence at secrecy about these experiments, for the only result of such tactics will be to hide useful information for a certain time from our own naval architects, whilst foreigners will certainly obtain all they require.

DISCUSSION.

Captain C. Penrose FitzGerald (Associate): Since writing this paper experiments have taken place which, I am informed, are to be kept secret, but I see no reason for altering the expression of opinion given herein. I cannot see the slightest advantage in trying to play blind man's buff with these matters in the present days of almost universal publicity.

Major N. Soliani (Member): Captain FitzGerald has in his paper remarked on the ships of the Italian Navy, and has said that high explosives would be very dangerous to them. I may say that experiments have been made in Italy with these high explosives, but nothing came out of them to shake the confidence of the Italian authorities in their policy regarding those ships. On the other hand, it is quite certain that the big ships have a greater capability of standing the effect of high explosives than small ones.

Mr. W. H. White (Vice-President): My Lord, I should be very sorry to sit here, and not express the feeling of gratitude which all those who have to do with war-ship construction must feel to Captain FitzGerald for giving us the benefit of his opinions and advice on a question of great importance. But I do not quite agree with his remarks that what is being done in the *Resistance* is hidden away from our English naval architects. Personally I have had the pleasure of seeing all that is to be seen in the *Resistance*. I am not at liberty to say what I saw, but so far as knowing what has happened there, I, as the responsible Admiralty Naval Architect, am most fully informed. I presume that whatever action may be taken in consequence of these experiments, will be a matter for decision by the Board of Admiralty, with all the facts before them, and the opinions of their naval and professional officers thereon. I am bound to add, while acknowledging the advantage of having Captain FitzGerald's opinions, that I do not quite see how public discussion, based on imperfect information, is likely to advance this matter very much. We have in this paper of Captain FitzGerald's the best information he can give us about what the French have done, and this is confessedly not authoritative or complete. He may be sure, and the country may be sure, that the Board of Admiralty, and its officers also, endeavour to ascertain what is being done, not merely in France, but everywhere else, not only in this matter of explosives, but in all other matters affecting war-ships. The history of the last thirty or forty years of war-ship construction shows that the Admiralty, and its professional advisers, have not been above taking useful hints from any quarter from which they might come. As to the advantages Captain FitzGerald supposes to arise from the French being quicker-witted and more imaginative than ourselves, we must remember the compensating advantage we possess in the United Kingdom in having associated with us a race (to which Captain FitzGerald himself belongs), which in regard to wit and imagination, and, I may add, humour, certainly does not compare badly with our neighbours across the Channel. Perhaps the balance of advantage is in our favour, bringing together, as it does, the qualities to which I have

alluded on the other side of the Irish Channel, and the solidity and common sense which are supposed to be characteristics of the people in this island. My next remark has nothing to do with high explosives, but it may cause an explosion of another kind, if I add that not a few of the instances in which France has taken the lead of this country have arisen from the Parliamentary system of Government under which we live. When we hear of the French having constructed the first steam line-of-battle ship, or the first sea-going ironclad, do not let it be forgotten that it is not due to Great Britain lagging in the race of invention, but to the fact that France had an Emperor who could say to Monsieur Dupuy de Lome, "Build me certain ships," and it was done. In England many years may be and have been occupied in debating whether we should have one description of ship or another. Of course, we are all admirers of the Parliamentary system of Government, but it has its drawbacks. I may remind this meeting of an event that is of some interest in this connection. Monsieur Dupuy de Lome came to England in 1844, and spent the greater part of two years here, visiting our Government and private dockyards, our engine factories, and noting what was being done in the development of steam navigation. Then he went back to France, carrying with him all the information which he had obtained, and became, under the Emperor's patronage, the leading French designer of steam-propelled war-ships. English engineers were really his guides and instructors; and France owed its lead to the exceptional opportunities given to him to carry his plans into execution, not to any quicker-wittedness, or greater inventiveness.

Admiral Sir John Hay, K.C.B., D.C.L., F.R.S. (Vice-President): My honourable friend, Mr. White, with perfect justice, is obliged to be reticent with regard to the recent experiments, and I make no reflection upon him on that account, for he is but doing his duty; but I am not by any means certain that it is an advantage to the country that the result of experiments of that character should not be given to a scientific institution. Signor Brin has permitted Major Soliani to give us information to-day which is very valuable indeed, although not on that point. I conceive it is the duty of the Admiralty, certainly, to reserve to themselves the knowledge of certain inventions; but the result of experiments might frequently be given more generously to the public, so that all minds might be brought to bear upon the question, which might be the means of our benefiting by those experiments. The experiments are at the public charge, and the public have a right to have the architects and engineers of this country informed of what has taken place, so that they may have an opportunity of assisting the enormous skill and ability which Mr. White possesses, and which is at his disposal for the proper determination of the question. The object of war-ships is to take care not to be destroyed or to disable themselves, but to destroy and disable as much as possible their opponents. Formerly, with regard to wooden ships, our instructions were to capture, and therefore we did not destroy if we could help it. Nowadays, the number of iron ships is limited, and the business of those who have to engage them is to destroy the enemy so as to prevent him from breaking in on our commerce, and to disable them so as to prevent them from effecting the damage which they are intended to effect on behalf of their own country. There are three methods of destruction. The ram is the most fatal instrument, if you could only be certain how you apply it, but you cannot always put salt on the tail of your bird. It is the most formidable of all, but you cannot be certain with regard to it. Then comes the question of artillery and of the high explosives, whether applied by the torpedo, not by pneumatic tubes, but by the ordinary explosive forces which Captain FitzGerald has mentioned in his paper. I think that we ought as soon as possible to know the result of these experiments which have been tried, and that we should not be kept in the dark with regard to the effect of these various explosive substances and the methods of applying them. Therefore, while recognising what Mr. White has said with regard to the instructions at present existing, I would suggest to him, with his liberal mind, that he should suggest

to those colleagues of his, with whom he acts with so much benefit to the country, that on an occasion like this he should obtain the same opportunity that Major Soliani has had with reference to the subject of his paper, of giving us the effect of these experiments, so that the gentlemen I have the honour to address might bring their minds to bear on the results of those experiments and make suggestions to counteract them, and if possible for making them more formidable in our hands and less destructive of the ships which Major Soliani or Mr. White, or any other capable shipbuilder, constructs for his Government. I thank him for initiating this discussion, and I hope we shall hear a general expression of opinion that experiments which are carried out at the public charge are not in the nature of inventions which it is well perhaps to retain in our possession, but should be given at least to scientific bodies, so that they may have an opportunity of assisting the country in coming to a right conclusion.

Mr. W. H. White : Just one statement, my Lord, by way of explanation. I think the meeting and Sir John Hay perfectly understood that I expressed no personal opinion, but simply stated my position in the matter. There is this other statement which I may make also by way of explanation, that these experiments on the *Resistance* are only now beginning, they are not complete.

Captain C. Penrose FitzGerald (Associate) : I am glad to hear from Major Soliani that these new inventions have not shaken his faith in the special method of construction of the Italian ships. I have on former occasions had the honour of expressing to this Institution my views with regard to the effect of quick-firing guns on designs which were formulated and laid down before they were in general use. I think it was in the spring of this year we had some drawings on the blackboard about it. It is pleasant to hear that faith in the designs is not shaken; but I have heard no reply to my objection with regard to the destruction of unarmoured water lines by quick-firing guns. Every new invention seems to point in the direction which I ventured to indicate at that time, namely, that if you destroy larger areas of water line the ship must upset or sink; but I will not go into that question again at present. Now about the secresy of these experiments. Mr. White says they are not kept secret from him. I did not think they were, but there are other naval architects in Great Britain besides the Admiralty naval architects : other eminent men who could initiate original designs, and bring their great minds to bear on the subject with great benefit to the country, if they were given the information which they ought to have, and we should not then be dependent on the genius of one or two men, however eminent, inside the Admiralty, for the designs of our ships; and though the experiments have not been finished, yet if it is the decision of my Lords to keep them secret they will do their best to do so. I am obliged to Mr. White for his delicate personal compliment to my countrymen. I think, according to Mr. White's own showing, we are likely to reap all the disadvantages of a Parliamentary Government by being kept ten years before we carry out what has been discovered by new experiments, while we have none of the advantages; the disadvantages of secresy, and of not having an Emperor to say, " Build a ship at once," so that we are terribly handicapped, as far as I can see, with all the disadvantages, and none of the advantages. Sir John Hay kindly supported my views on that subject. With regard to the ram, that is an old story, and I do not much believe in it. I think few men in their sober senses would go 16 knots an hour at each other in a couple of egg-shells; and if they tried I do not think they would succeed in hitting, and if they hit they would inevitably be both destroyed.

The President : Allow me to return our united thanks to Captain FitzGerald for his paper, which has started a new subject, and I am sure we shall know more about it by and by. My friend Mr.

White, the Chief Constructor of the Navy, has talked, to my utter amazement, about the pleasure it would give to him to see the destruction of one of his own ships. I have never before in my life differed from my honourable friend, but perhaps he will allow me on this occasion to say I entirely decline, speaking as a private individual on behalf of the tax-payers of this country, to share in that pleasure. Nothing would go to my heart more than to see any of Her Majesty's ships destroyed by one of those villainous, horrible things they call "explosives." Gentlemen, you are now free, and I only trust and hope that the weather will prove propitious, and that you will enjoy the excursion which I wish I could join in to-day, but cannot.

PROCEEDINGS IN LONDON.

INSTITUTION OF NAVAL ARCHITECTS.

APRIL 10, 11, AND 12, 1889.

INTRODUCTORY PROCEEDINGS.

THE Meetings of this, the Thirtieth Session of the Institution of Naval Architects, were held on the 10th, 11th, and 12th April, in the Hall of the Society of Arts, John Street, Adelphi.

The opening Meeting was presided over by the Right Hon. Earl of RAVENSWORTH, President of the Institution, who commenced the proceedings by calling upon the Secretary, Mr. GEORGE HOLMES, to read the report of the Council, which was as follows:—

REPORT OF COUNCIL, 1889.

The Council is able to report with much satisfaction that the prosperity of the Institution continues to make steady progress. During the year 1888 one hundred and ten new Members and Associates were elected; on the other hand, the losses due to death and resignation were seventeen, showing a net gain of ninety-three. Thanks to the large increase in the number of the Members, the finances of the Institution are in a satisfactory condition. The balances in hand at the end of the year show an increase of £155 19s. 4d., and the Library Fund has been increased by the investment of £500 in East India 3 per cent. stock.

As was announced in the last Report, the Council accepted a very cordial invitation from the President of the Institution of Engineers and Shipbuilders in Scotland, and from the Directors of the Clyde Steamship Owners' and Sailingship Owners' Associations, to hold a Summer Meeting on the Banks of the Clyde. The meeting (which was the second held by the Institution in Glasgow) took place on the 24th to the 27th of July last, and, like its predecessors held at Liverpool and Newcastle-on-Tyne, proved a great success. The Institution was received with the utmost kindness and hospitality, seven papers were read at the meetings, and excursions were arranged to the Forth Bridge Works, the Glasgow Harbour and Works, the International Exhibition, the works of Messrs. William Denny Brothers, and of the Steel Company of Scotland, and to Loch Fyne and Inverary Castle.

The best thanks of the Institution are due to those who provided so well for the instruction and amusement of the Members.

The Rules for the election of Vice-Presidents are now under the consideration of the Council, and proposals relating thereto will be submitted at the next General Meeting of the Institution.

It is with much regret that the Council announces the death of one of the original founders of the Institution, Dr. Joseph Woolley, M.A., LL.D., who died on March 24 last. Dr. Woolley always took the most active interest in the affairs of the Institution. The very first paper read before the Institution at its inaugural meeting was from his pen. He was one of the original Vice-Presidents, and was elected an Honorary Member in the year 1884 as a recognition of the eminent services which he had rendered to the Science of Naval Architecture. A biographical notice of Dr. Woolley will be published in the forthcoming Volume of Transactions.

The Council also regrets to announce the death of another Vice-President, Admiral the Hon. Arthur Duncombe, and of two former Members of Council, viz., Sir William Pearce, Bart., M.P., who was head of the Fairfield Shipbuilding and Engineering Company, Limited, and Mr. John MacMillan, Shipbuilder, of Dumbarton.

Institution of Naval Architects.

Dr. *Statement of Receipts and Expenditure from 1st January to 31st December, 1888.* Cr.

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance at Bankers, 31st Dec., 1887 ...				812	7	0
„ Do. in Secretary's hands, do. ...				33	8	1½
„ Annual Subscriptions	1,712	10	6			
„ Life Subscriptions	94	10	0			
				1,807	0	6
„ Sales of Volumes				161	10	11
„ Admiralty Grant...				250	0	0
				£3,064	6	6½

PAYMENTS.

1888.		£	s.	d.	£	s.	d.
Dec. 31	By Rent	200	0	0			
	„ Housekeeper and Cleaning ...	37	14	0			
	„ Printing Vol. XXVIII. ...	545	18	7			
	„ Photograph for Vol. XXVII...	11	10	6			
	„ Postage, Vol. XXVIII. ...	37	15	9½			
	„ Stationery	17	13	3			
	„ Insurance	2	10	0			
	„ Postages, Telegrams, and Petty Expenses	100	18	3			
	„ Salaries and Wages	613	1	4			
					1,567	1	8½
	„ Expenses of Meetings—						
	At London	15	2	6			
	At Glasgow	31	8	3			
	Advertising	55	4	6			
	Reporting	85	0	0			
	Gas	3	3	0			
					189	18	3
	„ Furniture				12	14	8
	„ Cash—						
	At Bankers ...				1,246	11	11
	In hands of Secretary ...				48	0	0
					£3,064	6	6½

LIBRARY FUND.

	£	s.	d.
To Balance at Bank, 31st December, 1887	471	13	6
„ Entrance Fees	212	2	0
„ Income on Investments on year's Interest on 2¾ per cent. Consols and India 3 per cent. Stock ...	22	19	6
	£706	15	0

1887.		£	s.	d.
Dec. 31	By Library Expenses	6	19	0
	„ Photographs of the late Mr. W. Froude and Mr. W. Denny	21	0	0
	„ Investments—India Stock, 3 per cent. ...	500	0	0
	„ Cash at Bankers	178	16	0
		£706	15	0

HENRY GREEN, *Treasurer.*
GEORGE HOLMES, *Secretary.*

We have examined the above written entries with the books and vouchers, and find them correct,

BALL, BAKER, ROWE & CO.,
Chartered Accountants,
1, *Gresham Buildings, E.C.*

The following is a List of Donations to the Library :—

"Transactions of the Liverpool Engineering Society," for 1888. *Presented by the Institution.*

"Proceedings of the Royal Society," for 1888. *Presented by the Royal Society.*

"Minutes of the Proceedings of the Institution of Civil Engineers," Vols. LXXXIX., XC., XCI., XCII., XCIII., and XCIV. *Presented by the Institution of Civil Engineers.*

"Proceedings of the Institution of Mechanical Engineers," for 1888. *Presented by the Institution of Mechanical Engineers.*

"Journal of the Iron and Steel Institute," for 1888. *Presented by the Iron and Steel Institute.*

"Journal of the Society of Arts," for 1888. *Presented by the Society of Arts.*

"Transactions of the Institution of Engineers and Shipbuilders in Scotland," Vol. XXXI., 1888-9. *Presented by the Institution of Engineers and Shipbuilders in Scotland.*

"Transactions of the Society of Engineers," for 1888. *Presented by the Society of Engineers.*

"Lloyd's Register of British and Foreign Shipping," for 1888-89. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Universal Register," for 1888. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Register of Yachts," for 1888. *Presented by the Committee of Lloyd's Register.*

"Annual Reports of the Royal National Lifeboat Institution," 1888. *Presented by the Royal Lifeboat Institution.*

"North-East Coast Institution of Engineers and Shipbuilders," Vol. IV., for 1887-88. *Presented by the North-East Coast Institution.*

"The Scientific Proceedings of the Royal Society of Dublin," for 1888. *Presented by the Royal Society of Dublin.*

"North of England Institute of Mining and Mechanical Engineers," for 1888. *Presented by the North of England Institute.*

"Engineer," for 1888. *Presented by the Proprietors.*

"Engineering," for 1888. *Presented by the Proprietors.*

"Iron," for 1888. *Presented by the Proprietors.*

"Iron and Coal Trades Review," for 1888. *Presented by the Proprietors.*

"Field," for 1888. *Presented by the Proprietors.*

"Army and Navy Gazette," for 1888. *Presented by the Proprietors.*

"Shipping World," for 1888. *Presented by the Proprietors.*

"Saturday Review," for 1888. *Presented by the Proprietors.*

"Marine Engineer," for 1888. *Presented by the Proprietors.*

"English Mechanic," for 1888. *Presented by the Proprietors.*

"Revue Maritime," for 1888. *Presented by the French Ministry of Marine.*

"Rivista Maritima," for 1888. *Presented by* H. Clauson, Esq.

"Proceedings of the Royal Society of Victoria," Vol. XXII. *Presented by the Royal Society of Victoria.*

"Germanischer Lloyd," for 1888. *Presented by* Mons. F. Schuler.

"Annalen Für Gewerbe und Bauwesen." *Presented by the Proprietor.*

"Wochenschrift des Oesterreichischen Ingenieur und Architekten-Vereines." *Presented by the Society.*

"The American Engineer," for 1888. *Presented by the Proprietors.*

"The Journal of the Franklin Institute," for 1888. *Presented by the Institute.*

"Proceedings of the United States Naval Institute," for 1888. *Presented by the Institute.*

"Ordnance Notes," for 1888. *Presented from the Ordnance Office, War Department, Washington, D.C., United States.*

"Registro Italiano per la Classificazione dei Bastimenti." *Presented by the Committee of the Registro Italiano.*

"Proceedings of the Royal Society of New South Wales," Vol. XX., 1888. *Presented by the Royal Society of New South Wales.*

"Annual Report of the Chief of Ordnance to the Secretary of War of the United States," 1888.

"The Life of William Denny, F.R.S.E." By A. B. Bruce. *Presented by Mrs. William Denny.*

"The Scientific Works of C. W. Siemens, Kt., F.R.S., D.C.L., LL.D." Vol. I.: "On Heat and Metallurgy." Vol. II.: "Electricity and Miscellaneous." Vol. III.: Addresses, Lectures, &c. *Presented by the Executors of the late Sir William Siemens.*

"The Life of Sir William Siemens, F.R.S., D.C.L., LL.D." By William Pole, F.R.S. *Presented by the Executors of the late Sir William Siemens.*

"The Mining Manual," for 1888. *Presented by Walter R. Skinner, Esq.*

"Marine Engines and Boilers." By G. C. V. Holmes, Esq. *Presented by the Author.*

The following gentlemen (having been duly recommended by the Council) were unanimously elected Members of the Institution:—Mr. Edwin Beaton, Assistant Constructor, Admiralty, Whitehall, London; Mr. Frederick Charles Bishop, Marine Architect and Surveyor, Messrs. Thomas Wilson, Sons & Co., Hull; Mr. Francis T. Bowles, Head of the Construction and Repair Department, Navy Yard, Norfolk, Va., U.S.A.; Mr. Thomas Henry Bridges, Consulting Engineer, Leadenhall-street, London; Mr. George Brown, Chief Draughtsman, Messrs. W. Denny & Brothers, Dumbarton; Mr. John H. Buchanan, Surveyor Lloyd's Register of Shipping, West Hartlepool; Mr. John Henry Cardwell, Assistant Constructor, Admiralty, Whitehall, London; Mr. George John Carter, Draughtsman, Sir W. G. Armstrong, Mitchell & Co., Newcastle-on-Tyne; Vicomte Gaston Clauzel, Member of the Corps du Genie Maritime, Paris; Mons. Huibert Cop, Professor of Naval Architecture, Polytechnic School, Delft, Holland; Mr. David Crichton, Superintendent Engineer, Messrs. Salvesen & Co., Leith; Mr. Albert John Durston, Engineer-in-Chief, Admiralty, Whitehall, London; Mons. Marc Julius Faruffini, Captain in the Royal Italian Corps of Naval Constructors, Spezia, Italy; Mr. George William Gill, Shipbuilder, Rochester, Kent; Mr. John Inglis, Chief Draughtsman, Messrs. Ramage & Ferguson, Shipbuilders, Leith, N.B.; Mr. Michael Kasy, Manager, Baltic Shipbuilding and Engineering Works, St. Petersburg; Mr. Alexander McAusland Kennedy, Assistant Manager, Messrs. A. M'Millan & Son, Shipbuilders, Dumbarton, N.B.; Mons. Govert Jacob Mees, Engineer, Bureau Veritas, Paris; Mr. Adam Miller, Naval Architect, London; Mons. K. C. Nielson, Director of Naval Construction, Royal Danish Navy, Copenhagen; Mr. Roland Philipson, Assistant Manager, North Eastern Marine Engineering Company, Limited, Wallsend; Mr. Cuthbert Potts, Consulting Engineer and Ship Surveyor, Sunderland; Mr. John Prentice, partner in the firm of Messrs. Boyd & Co., Engineers and Shipbuilders, Shanghai, China; Mr. Albert Edwin George Richards, Assistant Constructor, Admiralty, Whitehall, London; Mr. Francis Charles Simpson, partner in the firm of Messrs. Simpson, Strickland & Co., Shipbuilders, Dartmouth; Mr. Custance Bertram Timothy, Manager, Messrs. Forrest & Co., Shipyard, Wyvenhoe, Essex; Mr. John Tweedy, partner in the firm of Messrs. Wigham Richardson & Co., Walker-on-Tyne; and Mr. George Wiltshire, Works Manager, The Thames Ironworks and Shipbuilding Yard, Blackwall.

The following gentlemen were elected Associates:—Mr. Warington Baden-Powell, Mr. William Beardmore, Captain Rafael Blanco, Argentine Navy, Mr. Robert H. Brougham-Thomson, Mr. Henry Chapman, Mr. James Dixon Churchill, Captain William Crowder, Mr. Alexander Cunningham, Captain John J. L. Goodridge, Mr. Kedgwin E. K. Gough, Mr. Richard H. Green, Mr. George Thompson Henderson, Mr. Thomas Henderson, Captain George Hodgkinson, Mr. Robert Marshall, Mr. William Tyson Martin, Rear-Admiral Richard C. Mayne, R.N., C.B., M.P., Mr. Samuel Cotterill Newey, Mr. P. R. Parsons, Mr. George William Taylor, Mr. Philip Alexander Thomas, and Mr. Stephen Thompson.

Since the issue of Volume XXIX. the Institution has sustained the loss of the following Members and Associates:—J. J. Woolley, M.A., LL.D., Honorary Member; W. Dutton, Edward Faron, William Macmillan, Sir William Pearce, Bart., M.P., Thomas Summers, and John Trickett, Members; Admiral Arthur Duncombe, Admiral George Goldsmith, H. C. Rothery, Q.C., and Don P. de Satrustegni.

The Secretary next read the following list of names of the retiring members, and the new names nominated by the Council to fill up the vacancies for the Ordinary and Associate Members of Council for the ensuing year.* Retiring Members of Council: Mr. J. Macfarlane Gray, Dr. A. C. Kirk, LL.D., Mr. W. Parker, Mr. J. Price, Mr. J. I. Thornycroft, and Mr. H. H. West. New Candidates nominated for Members of Council: Mr. J. H. Biles, Mr. H. E. Brown, Mr. R. J. Butler, Mr. W. T. Doxford, Professor P. Jenkins, and Mr. W. Gray. Retiring Associate Members of Council: Mr. R. E. Froude and Mr. Dixon Kemp. New candidates nominated for Associate Members of Council: Mr. E. A. Cowper and Admiral A. F. R. De Horsey.

The President (Earl of Ravensworth) next put to the meeting the following list, containing the names of the President, Vice-Presidents, and Treasurer proposed for the ensuing year, and which was unanimously adopted:—The Right Hon. the Earl of Ravensworth, President; H.R.H. Admiral the Duke of Edinburgh, K.G., Kt., K.P., G.C.S.I., G.C.M.G., G.C.I.E.; The Right Hon. the Earl of Northbrook, G.C.S.I.; The Right Hon. Lord Brassey, K.C.B.; The Right Hon. Lord Armstrong, C.B., D.C.L., F.R.S.; The Right Hon. Lord George Hamilton, M.P.; Admiral the Right Hon. Lord John Hay, G.C.B.; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S.; The Right Hon. W. H. Smith, M.P.; Sir Nathaniel Barnaby, K.C.B.; Sir Frederick J. Bramwell, D.C.L., F.R.S.; Admiral Sir Alexander Milne, Bart., G.C.B.; Admiral Sir Frederick W. E. Nicolson, Bart., C.B.; Sir James Ramsden, Kt.; Sir Edward J. Reed, K.C.B., F.R.S., M.P.; Admiral Sir R. Spencer Robinson, K.C.B., F.R.S.; Sir James Wright, C.B.; Mr. F. K. Barnes, Mr. Peter Denny F.R.S.E.; Mr. Francis Elgar, LL.D., F.R.S.E.; Mr. Henry Green, Dr. A. C. Kirk, LL.D.; Mr. Benjamin Martell, Mr. Henry Morgan, Mr. George W. Rendel, Mr. Richard Sennett, Mr. John I. Thornycroft, Mr. W. H. Tindall, Mr. Bernard Waymouth, and Mr. W. H. White, F.R.S.; Mr. Henry Green, Treasurer.

The President then nominated Mr. James Dunn and Mr. W. H. M. Ellis as scrutineers, to examine the voting papers.

The President: Gentlemen, in accordance with custom, the usual custom of this Institution, I rise, with your kind permission, to address a few words to you in the shape of an opening address. And first of all, it too often falls to my lot to look at what I may call the dark side of the report, and to ask you to join with me in an expression of sympathy for those who have left our ranks at the call of nature during the past year. I am sure you will all join with me in expressing our sincere sense of the loss we have sustained in the death of Dr. Woolley. He was one of our original members, as has been described to you in the report, and his valuable labours will never be forgotten by the Council of this Institution, and by the members generally. The services which he has rendered to us will make our loss a very heavy one to bear, and I am sure I am only expressing your sorrow and sympathy for one who has departed from amongst us. There are other three names I will mention among our losses, and they are the names of a great and valued personal friend of my own, Admiral Duncombe, and the name of Sir William Pearce, who, in the vigour of his age, and the full possession of those energies and abilities which raised him to so high a position in society, has been taken from us. We have to lament his loss, and also to sympathise with his family in the loss which

* For List of Members of Council actually elected, see page 149.

they have sustained. There is also the name of Mr. Macmillan, well known to many of you—well known and respected by all our Scotch friends, and many of our English friends also. I know I am expressing your feelings when I express my own sorrow and sympathy in these severe losses which we have sustained.

I will now, gentlemen, turn, if you please, to what I may call the brighter side of our report; and I am very happy to be able to congratulate you all upon our own present position and prospects as an Institution. I may also, and I do so with the utmost cordiality, congratulate you all upon more than a comparative—a very substantial return of commercial prosperity. I think that, as a whole, our national interests—our great national industries—are in a condition of prosperity which has not been known for several years past. The tide has turned, and I hope and trust that you may all benefit, and that all the other interests which are associated with this Institution—which are many—and the great industrial interests of the country generally, may enjoy that prosperity to the full. But there is, perhaps, no branch of national industry in which that activity, which at present is prevailing, is more marked than in that of shipbuilding, and, of course, associated with it, the business of the marine engineer. I do not think that I am using any term of exaggeration when I say that I believe all our great shipbuilding establishments are at this moment actively engaged, and that their prospects for at least the present year are of a very favourable character. I trust that that may continue, and when we look a little forward, seeing we have in prospect a large amount of Government work, which I rejoice most cordially to think is to be largely shared in by those private establishments, I think that the prospects for the future, extending considerably beyond the limits of the present year, may also be considered highly favourable. If we turn—which I will very shortly, because I do not want to trouble you with many figures to-day—to the return of Lloyd's Register, we find that at the commencement of this year there were under construction 445 merchant steamers, of an aggregate tonnage of 811,000 tons in round numbers. And this is a point that I should like to emphasise, that more than seven-eighths of that total were steamers—and steel is the material for seven-eighths of that quantity. Now, there are characteristics in reference to steel as to which I should just like to make this one remark: We have heard a good deal lately, and public opinion has been a good deal aroused and excited by certain reports which have reached us of the condition of the plates of the *Nile*, and the effect of corrosion on those plates, in consequence of the paint having stripped off, and I am glad to observe that on the list of papers to be read this year there is a paper upon "Corrosion" coming from a most valuable source, and, perhaps, nobody in the room is better qualified to deal with it than the author of that paper. I think it is a most opportune paper, and one which the country will hail with considerable satisfaction. But there is another characteristic which I, having been connected all my life with the interests of the Mercantile Marine, and living in a part of the country where such a vast amount of the cargo tonnage of this country is built, wish particularly to call attention to, and I think it is not out of place that I should do so—that is, the great improvement, the great progress, that has been made already, and is being made, in the structural strength of our cargo steamers, and what is still more satisfactory to observe—and I make this remark especially in connection with the work of this and similar Institutions—is that these great improvements in our cargo ships are not at all the result either of accident, or guesswork, or conjecture; but these improvements are being effected by careful calculations by our shipbuilders of the strains produced upon different sections of the ship at sea, and by provision being carefully made to withstand those strains. I make that announcement with some confidence, and I think that that is a most satisfactory feature in the present building of our cargo vessels. I could confirm it by evidence, but I do not wish, unnecessarily, to detain you to-day; but I think that, when wild and reckless statements are made from time

to time, it is right and just that the efforts and energies and talent of our shipbuilders and shipowners should receive from time to time something like public recognition, and nobody can doubt that the work of this and similar institutions, such as exist on my own river, the Tyne, and also on the great port of Clyde and other places, the admirable papers that are written, the difficult and complex problems that are solved, have been taken into account by our shipbuilders, and the admirable and vigilant supervision exercised by Lloyd's in the construction of our merchant vessels—I say, nobody can doubt that all these circumstances are bearing admirable fruit; and, therefore, I am able to congratulate you upon one of the very great results arising from the labours of this and similar institutions in connection with the shipbuilding of the country. I think it is right that we should recognise the intelligent appreciation by our shipowners of the information so disseminated, and that a fair share of credit should be assigned to them for the success of those efforts and of that intelligence; but, gentlemen, while our shipowners and shipbuilders are engaged in the great work of improving our Mercantile Marine, which I may say, without exaggeration, covers every sea and crowds every port in the world—while these improvements are being made, and while every effort is being made to meet the wants of commerce—because we are led to hope and believe that trade is improving, not only in our own country, but in all other countries in the world—while these efforts are being exercised, still we must not forget that some of the most important and powerful maritime countries in the world are showing at this moment unusual activity in the construction of a class of vessels which are called commerce destroyers. I do not particularise, because it would be invidious to do that; but it is a very well-known fact. That word is rather an ugly word, but it has a very deep signification for us; and, therefore, I am quite sure the English public, the taxpayers of the country, will not grudge the efforts—the praiseworthy and patriotic efforts—which are about to be made by the Admiralty, who are responsible in that particular respect to the country, to perform their duty, and to protect our commerce. That leads me at once, gentlemen, to ask your permission for a very few minutes to refer to the Admiralty programme which is now before the country, and to be allowed, in a few sentences, to notice the circumstances under which the paper, which you will see by the programme is to be read by the Director of Naval Construction to-day, will be read to you. It is a very extensive scheme, the Admiralty programme of building for the year, and it is a continuous programme, and that continuous policy has practically been already endorsed by Parliament. The paper that is going to be read to you is a paper upon the designs of the battle ships which are to compose what will practically be a new fleet, and a most powerful fleet, when the Admiralty's proposals are completed. Now, I do not think that anybody will refuse to agree with me that those designs (you see them upon the walls) come before the country with very high credentials indeed. I hardly know myself what higher credentials you could expect. It was in the month of August last—I think I am correct—that the Board of Admiralty met for the purpose of considering and laying down the conditions for the building of those vessels, and the Board of Admiralty had at that time before them, not only the most approved types of vessels composing Her Majesty's Navy, but they had also before them, as I understand, the most approved types of foreign ships. It was in November that the Admiralty met again, and they agreed upon certain main conditions that those vessels should fulfil. The designs were prepared by the Director of Naval Construction, aided by his very accomplished staff; and when I speak of the Director of Naval Construction, I claim no more than his due when I say that he stands at the very head of his profession; that he enjoys the reputation of an eminent naval architect, not only in this country, but in all other countries of Europe, and that he possesses the absolute and entire confidence—and this is a much more important point for you as Englishmen—of the Board which employ him. Well, these designs have met with severe and stringent criticism. Now, I am quite sure that every

man in this room will agree with me that criticism is a most valuable thing, and I cannot conceive any well-advised Board of Admiralty seeking otherwise than to court criticism rather than to condemn it, and I think the Admiralty have taken a very wise course; and, certainly, they have paid this Institution a very great compliment, in permitting a discussion upon these designs to take place within these walls. But I would like to say this: valuable as we all admit criticism to be, it is essential in the very nature of things that, if criticism is to be valuable, it should be fair; and, in order to be fair, there are certain leading considerations which must be kept carefully before the mind. The art and duty of a critic is a very difficult and a very responsible duty to perform, and it strikes me that the first point to be borne in mind is the rapid progress of science. That progress is so rapid that it is exceedingly difficult for any Board of Admiralty, or any shipbuilder, private or other, to follow, and it is almost absolutely impossible to keep up with it, and I think that it is in the pursuit of science that very great injustice in the past—I speak this as only my own private opinion, and you will take it for what it is worth—has been done to the naval architect. Ships have been laid down, kept upon the stocks sometimes six, sometimes seven, and even as long as eight years, additions have been insisted upon, alterations have been required to be made which the naval architect when he designed the ship never contemplated, and by the time the ship is launched and sent to sea great changes in her draught of water, and consequently changes in the position of her belt or her side armour, however it may be distributed, have taken place. You ought not in justice to condemn the naval architect because the ship presents a different appearance to that which he contemplated when he designed her. All I think it is fair to ask a naval architect in these days of progressive science to do is this: to take the best type of ship that exists, to have it before him, to remedy ascertained defects, and to supply deficiencies shown by experience to exist. I do not think you can do more, because if you require him to do more than that you inevitably force him into the region of conjecture and possible speculation—not speculation in the ordinary sense of the term—but speculative ideas—the region of idea rather than the region of practice and experience, and I need not say that that is an exceedingly dangerous region to travel in. But, gentlemen, there are other considerations which I think must be kept in view, and those are the great and complex combinations which a modern fighting ship is required absolutely to contain within itself. There are, first, the conditions of stability, sea-worthiness, handiness, and minute subdivision. That is a pretty large combination, but it has to be made and effected. Then comes the combination of the maximum offensive and defensive power. Then comes the combination of speed, coal endurance, and the facilities (and this is rather an important point, although it is not so often dealt with) for re-coaling our fighting ships when at sea. We have heard lately complaints made by naval officers that those facilities in many of our earlier ironclads do not exist. That is another combination. Then comes the combination of the distribution of the armour, and that has been greatly complicated, I apprehend, of late by the enormously increased force of the modern explosive, or modern explosives, and their effect not only upon the outside, but also upon the inside of ships. Then comes the distribution of the armament—the guns. That has been very much complicated by the addition of the powerful auxiliary armaments with which our fighting ships have now to be provided in the shape of the rapid-firing guns, and that involves the great difficulty, first of all, of giving the guns the proper elevation above the deck, in order to effect concentration of fire, whether upon the broadside, or whether forward or aft, and then the greatest care must be taken that the fire of no one gun, or set of guns, interferes with that of another. Well, of course, there are many problems to be solved and provided for in our line-of-battle ships which will probably be explained to you in the paper, which you are all, I am sure, anxious to hear, and which I should be perfectly unjustified in detaining you any longer from hearing. I take these to be the leading combinations, and I only point them out for the purpose of

my argument, namely, that all these, and many other considerations, must be borne in mind when anybody, however able, however competent, however experienced, undertakes to criticise the designs of our line-of-battle ships. These matters, and many others, will form the subject of the paper which will be read to you to-day, and that paper, I apprehend, will be a reply to the criticisms that have been made of those designs, and an explanation of the purposes of those designs. All I can undertake to say—and I say it with the most complete confidence—is that that reply and those explanations will be conveyed to you in terms as clear, as candid, and as complete as the English language will admit of; it will be, gentlemen, for you, each and every one of you, to judge for yourselves whether the reply is a satisfactory one, and whether the explanations given are clear and convincing. You will all have that opportunity, and therefore I leave that part of the subject. I have merely put these few points before you, and I thank you very much for the kindness with which you have permitted me to do so, and I will now conclude by expressing, not a hope, but a firm belief, that the discussion will be a thorough, a searching, and a satisfactory discussion. That it will be conducted upon the principles—the noble principles, I may say, that always mark the debates in this Hall; with that temper, that tact, and that regard for the feelings of others, even although they may happen to be our opponents, which ever mark our discussions, I am perfectly confident. But it will be necessary, gentlemen, and the Council have had this matter before them, and have made provision, as they hope, for its accomplishment in some degree—to a considerable degree to depart from the spirit, or rather the words, of our rules. I wish the discussion to be a thorough discussion, and, therefore, I must ask your permission in some degree—a considerable degree, probably—to relax the severity of our rules with regard to the length of speeches. But, gentlemen, I must also ask this of you, that if you give me that discretion, if I think that any one speech, coming from what quarter it may, rather goes beyond the bounds of moderation, it will be my duty to appeal to you to signify in a quiet way that you have heard enough from that particular person. I shall appeal to you with confidence, but I wish in the exercise of the authority with which you vest the Chair on this and other occasions, to be allowed to exercise as far as I am able, my own discretion in these matters; because it must be apparent to you all, I think, that our rules are extremely valuable rules, and when we relax them it is only on special occasions, and I need not remind you of the old saying that "the exception proves the rule." I shall appeal to you to support me if any of the circumstances which I have gently hinted at should happen to occur. Now, I thank you, gentlemen, for your kind indulgence. Perhaps I have intruded upon you too long, but there are certain matters unconnected with the immediate subject of to-day which, I think, at any rate should be recognised in an Institution of this kind. I have ventured to dwell upon them in the fewest words I possibly could find, and before I sit down I will call upon the Director of Naval Construction to read his paper.

There is one word more, gentlemen. Inasmuch as we have a paper promised us from that eminent authority, Sir Nathaniel Barnaby, to-morrow, which deals specifically with the distribution of armour, any gentleman who may be pressed for time will have an opportunity on another occasion—that is, to-morrow—of addressing himself to that particular feature of the question which is quite sure to be involved in Mr. White's paper. That is a loophole which, no doubt, some gentlemen may wish to avail themselves of, and it is my duty to point it out to you. (Applause.)

RESULT OF THE BALLOT FOR THE ELECTION OF MEMBERS AND ASSOCIATE MEMBERS OF COUNCIL.

Institution of Naval Architects, 5, Adelphi Terrace, London, W.C.,
April 11*th*, 1889.

My Lord,—We have examined the Ballot Papers for the Election of the new Council, and, taking into account that three vacancies have been created in the Council by the election of Dr. Kirk, Mr. R. Sennett, and Mr. J. I. Thornycroft as Vice-Presidents, we find that the following gentlemen have been elected Members of Council :—

West, Mr. H. H.	Butler, Mr. R. J.	Parker, Mr. W.
Jenkins, Professor	Gray, Mr. Macfarlane	Price, Mr. T.
Biles, Mr. J. H.		

And the following Associate Members :—

Froude, Mr. R. E. | Kemp, Mr. Dixon.

We remain, my Lord,

Yours faithfully,

JAMES DUNN,
W. H. M. ELLIS,
Scrutineers.

ON THE DESIGNS FOR THE NEW BATTLE-SHIPS.

By W. H. White, Esq., F.R.S., Assistant Controller of the Navy and Director of Naval Construction; Vice-President.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 10th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

It has been the practice in this Institution, from its commencement, to devote no inconsiderable part of the proceedings to discussions relating to war-ship construction generally, and to the Royal Navy in particular. Including among its members as it does many most eminent naval officers, as well as the leading shipbuilders and marine engineers of the world, no better opportunity can be secured for the investigation of the scientific and professional questions incidental to war-ship design. On many previous occasions members of the Institution occupying the position which I have now the honour to hold, and gentlemen occupying equally responsible positions in foreign navies, have brought forward descriptions of new types of ships, or problems arising out of their official work, and always with advantage to the public service, as well as to the Institution.

Recognising the great interest which is now being taken in the designs of the eight first-class battle-ships which are proposed to be added to the Navy, and feeling convinced that no equally suitable opportunity could be obtained for replying to criticisms of the designs which have appeared in the public press, I applied for and obtained permission from the First Lord of the Admiralty to prepare this paper.

Its principal object is to describe the main features of the approved designs for these battle-ships, and to contrast their protection, armament, speed, and coal endurance with the corresponding features in other battle ships designed during the last twenty years. Incidentally it will be made clear that there are good reasons why these ships surpass in size any previously constructed vessels of the Royal Navy.

As I proceed with the description, it will be my endeavour to deal as fairly and candidly as possible with the adverse criticisms which have been launched against certain features of the designs, and to show that they are not well founded. In doing

this I shall treat chiefly of matters of fact, and as to matters of opinion shall describe the reasons which led to the decisions embodied in the designs. On these matters of opinion we shall probably hear much more in the discussion which will ensue.

The "action taken by the Board of Admiralty with regard to the preparation of designs" for these battle-ships is fully described in Parliamentary Paper C 5,635 of 1889; and a general description of the designs appears in the "Statement of the First Lord of the Admiralty explanatory of the Navy Estimates 1889-90 (C 5,648)." I need not reproduce the particulars of the procedure followed; but it may be safely said that no designs prepared at the Admiralty or elsewhere have ever received more thorough and careful consideration by competent authorities.

The choice eventually made by the Board was made from amongst a considerable number of alternative designs, and in full view of the most recent types constructed, or in course of construction, for the Royal Navy and for foreign navies. Before coming to a decision, the First Lord convened a meeting, attended not merely by the members of the Board, but by a number of most distinguished and experienced naval officers. At this meeting were discussed *seriatim* the several features that should be embodied in the design of a first-class battle-ship—speed, disposition and nature of armament, distribution of armour, protection of heavy guns, freeboard, &c. On each of these points the opinions of the officers present were ascertained. Subsequently the Board issued instructions as to the designs which were to be worked out in detail with a view to building the eight ships contemplated in the programme.

Two designs have been prepared and approved by the Board. In both designs are embodied identical qualities; so far as relates to the disposition (in plan) of the armament; the number and calibre of the heavy guns; the nature, disposition, and protection of the auxiliary armament; the distribution and thickness of the hull armour; the propelling machinery, speed and coal supply; the complement and equipment; magazines and transport of ammunition; and arrangements for hold-stowage. In principal dimensions and displacement the two types are identical. The essential differences are that while one design is for a turret ship with moderate freeboard at the extremities, and with guns about 17 feet above water, the other is for a barbette ship with the guns carried about 6 feet higher, and with high freeboard at the bow and stern.

It will be convenient to preface a description of the designs by the consideration of the *disposition of the armament;* a matter of the highest importance, which necessarily exercised great influence upon other features of the design, including (as will be shown hereafter) the distribution of the armour.

Alternative Dispositions of Armament.

The Board took into consideration all the principal dispositions of armament adopted in recent years for battle-ships, as well as several proposals that have been made—some of which have been patented—but not yet carried out in practice. It may be of interest and assistance in the discussion if I briefly summarise and illustrate some of the more important of these arrangements; and for this purpose a series of diagrams (Plates X.—XXIV.) have been prepared. On these diagrams the arrangement of the armour is also indicated.

Plate X. shows the disposition of the armament of the *Sultan*, designed in 1868. Practically the whole of the armament is contained in a central two-storied battery placed amidships, and associated with a water-line belt of armour. Other illustrations of the "belt and battery system" need not be given, as it is well known.

Plates XI. and XII. show respectively the arrangements carried out in the "breastwork monitors," *Devastation* and *Thunderer* designed in 1869, and proposed for the *Fury* in 1870. Here a low freeboard is adopted for the greater part of the length; and the two turrets, each containing two guns, are placed at the ends of the armoured breastwork, which is of less breadth than the ship. This design for the *Fury* was cancelled, and work upon the ship stopped at an early stage. The vessel was entirely re-designed in 1872 (see Sir N. Barnaby's Paper in *Transactions* for 1873), and became the *Dreadnought*, which is illustrated in Plate XIII. In all these designs the disposition of the armament is identical: and in securing the "all round fire" of the turret guns it was made practically impossible to carry any effective secondary armament.

Plate XIV. shows the *Inflexible;* a central citadel ship with turrets placed *en échelon.* In some of the later ships of this type an endeavour has been made to carry a few 6-inch guns as well as light quick-firers on the superstructures; but, as in the previous disposition, the means taken to secure large arcs of command for the heavy guns reduced greatly the efficiency of the secondary armament. Plate XV. illustrates the arrangements of the Italian citadel-turret ships *Duilio* and *Dandolo;* and Plate XVI. those of the German citadel-barbette ships of the *Sachsen* class.

During the period 1869-78 very little was done in the designs of H.M. ships in the direction of providing for a numerous and effective secondary armament; but this was not true in foreign navies, and particularly in the French Navy.

Plates XVII. and XVIII. show the principal features in the disposition of armament in a large proportion of the French battle-ships. There are four protected stations, each containing a heavy gun with a large arc of training. At a lower level are placed a number of guns of moderate calibre, sheltered to some extent from the fire of the heavy

guns. A very similar arrangement to Plate XVIII. has been adopted in the *Imperieuse* and *Warspite* of the Royal Navy, where considerable experience has been gained of its practical working.

Another typical disposition of the armament is illustrated by Plate XIX., which represents broadly the arrangements adopted in the Italian battle-ships *Italia* and *Lepanto*. Here the four heavy guns are carried *en barbette*, high above water, at the ends of a single armoured enclosure placed near the middle of the length of the ship; nearly the whole upper deck forming a glacis, over which these guns fire if the full arcs of training are obtained. The auxiliary armament is chiefly carried on the main deck, and sheltered by the upper deck from the fire of the heavy guns.

It will be remembered that in the design for an American battle-ship, described by Mr. John in a paper read before the Institution last year, a somewhat similar disposition of the armoured battery or citadel was adopted, but in association with turrets, and with a different arrangement of the auxiliary armament and upper works.

Plate XX. represents the Russian battle-ship *Catherine II.* In this case the battery is of large extent, and at each of the corners pairs of heavy guns are mounted *en barbette*, on the disappearing principle. The upper deck is a glacis for their fire, and the auxiliary armament is placed below this deck.

Plate XXI. represents the disposition of armament in the *Admiral* class. Here the secondary armament is greatly developed and mainly carried in a central battery between the two protected stations containing the four heavy guns.

Plate XXII. illustrates the very similar arrangements (in plan) adopted in the *Nile* and *Trafalgar*. It will be seen that in these vessels the central battery is shorter, and the secondary armament less powerful, than in the *Admirals*.

Plate XXIII. illustrates one of the various arrangements proposed by Sir Edward Reed, under his patent, No. 12,479, of 1887, but not adopted, I believe, in any ship yet built.

Plate XXIV. illustrates a patented arrangement of Sir N. Barnaby's (No. 7,759, of 1888) for securing in ships of relatively small size "an all-round fire from a single position, the guns being armour-piercing, and the armour defending them being as thick as that usually employed for the defence of the emplacements of heavy guns in large battle-ships." The diagrams given in the patent specifications do not indicate the disposition of the armour in an actual ship, but, as it is explained that the funnel is to come up through the centre of the platform carrying the guns, it is obvious that the armoured tower must be placed near the centre of the length of the ship, and that practically the whole of the upper deck must be treated as a glacis over which the guns must fire. So

that any auxiliary armament which might be carried would have to be placed below this upper deck. There are other features in the plan in relation to protection, buoyancy, and stability to which it is unnecessary to make any reference in this connection.

It will be understood that for the present purpose I am dealing only with these various dispositions of armament *in plan*, and am not discussing the very important question of *heights of guns above water*, to which reference will be made hereafter, as well as to the arrangements of armour plating indicated on the diagrams.

Disposition of Armament in New Designs.

After careful consideration of these and other alternative arrangements, the Board laid down the following principles for the new designs :—

"(1) That there should be four heavy guns placed in two protected stations, situated at a considerable distance apart, each pair of guns having an arc of training of about 260°, equally divided on each side of the line of keel. All four of these guns to be available on each broadside.

"(2) That the greater portion of the auxiliary (or secondary) armament should be placed in a long central battery, situated between the two heavy gun stations, and so disposed that there should be practically no interference with the fire of any one gun by that of any other.

"(3) That in view of the development of high explosives, it was desirable to secure the widest possible distribution of the guns in the auxiliary armament; and that it was preferable to mount the auxiliary armament on two decks, one of them being the spar deck, rather than to carry the guns chiefly between decks."

The reason for this decision will be found in the Parliamentary Papers above mentioned. It may be well, however, to briefly summarise the most important points of the discussion.

Under modern conditions, with quick-firing guns and high explosives in rapid development, it is essential to provide every battle-ship with a numerous, powerful, and well-placed auxiliary armament, in addition to her heavy guns. The disposition of the armament must be such that, while giving great command to the heavy guns, their fire shall not interfere with, or be dangerous to, the lighter guns and their crews. Provision must be made, in fact, for the safe and simultaneous working of all the guns, under the excitement of action, when precautions, which may answer fairly well at drill, cannot be certainly enforced.

Reviewing all the dispositions that have been adopted or proposed, it was seen that the disposition illustrated in the *Admiral* and *Trafalgar* classes was superior to all others in the fulfilment of these essential conditions, and it had other advantages.

Experience in the *Imperieuse* had shown that the system of *distributing* the heavy guns in several armoured positions involved a considerable interference with the efficiency and power of independent action of the auxiliary armament. Moreover the multiplication of protected positions for the heavy guns involves a considerable additional weight of armour for a given thickness as compared with what suffices for the defence of a less number of stations each containing two guns.

On the other hand, the principle of *concentration* pushed to an extreme has serious disadvantages and drawbacks, although it enables greater thicknesses of armour to be used within any fixed limit of weight, since it reduces the area to be protected. These objections were considered to outweigh the advantages, and are stated in the Parliamentary Papers as follow :—

(1) The great risk of the principal armaments being placed *hors de combat* by the explosion of a single heavy shell within or under the armoured enclosure.

(2) The enormous difficulties which this disposition of the main armament introduces into the efficient working of a powerful and numerous auxiliary armament.

Experience gained with the vessels of the *Admiral* class has as yet been limited, but it has confirmed the good opinion formed at the stage of design as to the merits of the disposition of the armament ; and, so far as I am informed, the general feeling amongst gunnery officers in the service is that the system is best adapted for modern requirements. We may anticipate that on this point the discussion will afford the Institution an opportunity of hearing the opinions of naval officers.

I will only add a suggestive fact, mentioned in the Parliamentary Papers :— "In some of the most important foreign Navies, where one or other of these modes of disposing the armament had been adopted, and the principles either of extreme distribution or of relative concentration had been carried out, the latest designs had contained arrangements similar to those decided upon as best for future battle-ships in the Royal Navy, which disposition is also to be found represented (in plan) in vessels like the *Trafalgar*, and in the *Admiral* class."

Referring to Plates VIII. and IX., and to the tabular statement, it will be seen that the disposition and character of the armaments in the turret and barbette designs are practically identical. The barbette ship, being of higher freeboard at the extremities,

can carry a few more 6-pounders, quick-firers ; and her heavy guns are, as before stated, 6 feet higher. But in plan the dispositions are the same, and the secondary armament in the central battery identical.

Number and Calibre of Heavy Guns.

It has been decided that each ship shall carry four 13½-inch 67-ton guns as the principal armament, with hydraulic apparatus for training, elevating, and loading the guns. The grounds for this decision are stated as follows :—

" There was a considerable weight of opinion that a 12-inch gun of modern design, and of about 50 tons in weight, might be made, which would possess sufficient power for most purposes ; but as no such gun was in existence, and as guns of 75 tons in weight were carried in existing foreign ships, while the 67-ton 13½-in gun was thoroughly successful, and all the details of the ammunition and mounting had been settled ; it was generally agreed, that for the three leading battle-ships, 67-ton guns were to be preferred for the heavy armament."

This decision has since been applied to all the ships.

In the number and power of their heavy guns the new ships will, therefore, stand on the same footing as the *Nile* and *Trafalgar*, or the four vessels of the *Admiral* class —*Rodney*, *Howe*, *Anson*, and *Camperdown*.

The height of the turret guns above water in the *Trafalgar* as designed was 15 ft. ; in the new turret ship it will be 17 ft. With the thick armour used for the protection of the turrets and turret bases, this apparently small change in the height of the guns above water involves an additional weight exceeding 150 tons.

In the barbette ships the heavy guns will be 23 ft. above water.

Auxiliary Armaments in the New Ships.

While the heavy gun armament is practically identical with that of preceding ships, the auxiliary armament is of unprecedented weight and power. In the Tabular Statement the facts are set out, but I must add some remarks, as there has been serious misunderstanding on this matter.

For example, in a letter published in *The Times* of March 22, Sir Edward Reed, in comparing the new designs with the *Trafalgar*, said :—" There is a small increase in the minor armament. . . . The increase of minor armaments is too small to dwell upon in this connection."

I will endeavour to show how mistaken is the view thus publicly expressed.

As designed, the *Nile* and *Trafalgar* were to carry eight 5-in. guns, besides a considerable number of small quick-firing guns and boat guns. The total weight of this auxiliary armament was a little less than 140 tons. A very short central battery sufficed to contain this armament.

During construction, six 4·7-in. 45-pounder quick-firing guns have been substituted for the eight 5-in. guns. This reduction in the number of guns has been accompanied, however, by an increase in the total weight to about 185 tons, the Service regulations providing for a very large supply of ammunition for quick-firing guns.

Turning to the new battle-ships, it will be seen that they are each to carry ten 6-in. 100-pounders, besides a considerable number of smaller quick-firers. The 6-in. quick-firing gun is still in the experimental stage; it will be adopted in these ships if successfully worked out, and weight has been taken for it. So far as *weights* are concerned, these ten 6-in. guns, with their mountings and ammunition, represent no less than 20 *guns of the same calibre*, with the allowance of ammunition hitherto carried.

The total weight of the auxiliary armament in the new ships is about 500 tons, or considerably over *three times* the weight originally assigned to the corresponding armament in *Trafalgar*, and *two and two-third times as great* as the weight of auxiliary armament to be actually carried by that ship.

I may fairly claim that such an increase is not properly described as "small" or "too small to dwell upon." On the contrary, to provide for it has proved one of the principal problems in the design. And those familiar with war-ship construction will know well that in stopping short, as I have done, at a comparison of weights of guns, mountings, and ammunition in the two designs, I have greatly under-stated my case. For example, to accommodate this auxiliary armament a central battery has to be provided about 170 feet in length, whereas in the *Trafalgar* the central battery is not quite 110 feet in length. The more numerous and powerful 6-in. guns, of course, require considerable additional weights to be worked into magazines, armament fittings, gun supports, &c. And with this increase in armament there has necessarily been associated an increase in complement of over 100 men, as compared with the *Trafalgar*, together with the weights for provisions, stores, and accommodation corresponding thereto. Were these extra weights, which are inevitable when the auxiliary armament is accepted, totalled up, the result would constitute a very large addition to the already large excess which the new ships have to carry.

To members of this Institution I need hardly add that such an addition to the *load* to be carried, *at a given speed, and on a fixed draught of water*, must involve an increase in the size of the ship, very sensibly exceeding the mere increase in load.

Before leaving this part of my subject, I would call attention to the fact (apparent in the tabular statement) that the weight of the auxiliary armament in the new battle-ships is practically equal to the total weight of armament proposed for the *Fury* design in 1870, the latter ship being of nearly 10,500 tons displacement.

I would also make the following extract from the Parliamentary Papers, although it is not possible for me to give any details at present :—

"A liberal allowance of weight has been made (in the design) for the protection of the guns, and the guns' crews, as well as for the rapid transport of the ammunition, and its protection in all the stages of its passage from the magazines to the guns."

Armour Protection of New Turret Ship Design.

This cannot be better described than by the following extract from the First Lord's statement to Parliament :—

"The armour protection of the hull proper includes two principal features :—

"(1) A belt, 8½ feet broad, extending over two-thirds of the length of the vessel, and having a maximum thickness of 18-inch armour. Transverse armoured bulkheads complete the belt, a 3-inch steel deck is fitted above it, and a strong protective under-water deck completes the protection before and abaft the belt.

"(2) The broadside above the thick belt is protected, to a height of about 9½ feet above water over a considerable portion of the length, by 5-inch armour. Screen bulk-heads similarly armoured enclose the central battery.

"The protection of the heavy guns consists of 18-inch armour on the turrets, and 17-inch on the redoubts protecting the turret-bases, &c."

The diagrams on Plate VIII. will make this description clearer. It will be seen that each turret stands in a separate battery or redoubt, which rests upon the protective deck, and is strongly armoured for the defence of the turret bases and loading apparatus. This system has been previously carried out in the *Victoria* and *Sans Pareil*, in each of which there is only one turret.

The belt armour rises 3 feet above water and extends 5½ feet below water. Its longitudinal extent is sufficient to ensure that if the spaces before and abaft it and

above the under-water protective deck were flooded, very small "sinkage" and very moderate "change of trim" would ensue. The maximum thickness of the belt armour is 18 inches, as against a maximum of 20 inches in the *Trafalgar;* the minimum thickness at the ends of the belt is the same as in *Trafalgar*—14 inches. The proportion of the length protected by the belt is the same in both cases.

Above this thick armour belt and protective deck, the broadside is armoured with 5-inch steel for a length of 145 feet and to the height of the upper deck amidships (9½ feet above water). Oblique armoured bulkheads or screens extend across the protective deck, and meet the redoubt armour: thus completely enclosing a lightly armoured citadel with its top at the level of the upper deck (9½ feet above water) having the same extreme length as the central battery, viz., 170 feet. Within the 5-inch steel armour on the sides coal-bunkers are built, extending from the belt to the upper deck, and having an athwartship thickness of 10½ feet. When filled with coal these bunkers would greatly reinforce the defence; when empty the minimum defence is 5 inches of steel, which is proof against all the smaller natures of quick-firing guns, and against many of the most destructive forms of attack from much larger guns.

In the *Trafalgar* (as illustrated on Plate XXII.) the two "turrets stand at the ends of a long armoured citadel extending to the full breadth of the ship: with vertical armour on the sides (varying in thickness from 16 to 18 inches) rising to a height of about 11 feet above water" according to the original design. In the completed ship this height will be about 10 feet. The upper deck over the citadel is plated with 3-inch steel. The distance between the centres of the two turrets is about 150 feet: and the central battery between the two turrets (as already stated) has an extreme length of less than 110 feet and a length along the broadside of about 65 feet.

In the new turret ship (as explained on page 157) it has been necessary to provide a much longer central battery (about 170 feet in extreme length) to accommodate the more numerous and powerful guns in the auxiliary armament; and the turrets are placed about 200 feet apart. Consequently, if the citadel system embodied in the *Trafalgar* had been repeated, the length of the thickly armoured sides would necessarily have been considerably increased; and a great additional weight and cost of armour, &c., would have been incurred if the same thicknesses had been maintained; or a considerable thinning of the armour, &c., made necessary if the same total weight had been adhered to.

No point in the new designs received more careful consideration than this. In order to elucidate the matter, alternative designs were prepared for ships of the same displacement, identical in all respects, except as regards the adoption of the "citadel" or the "separated redoubt" systems. Some of these designs are described in the Parliamentary Papers; I will briefly note one instructive comparison.

Two outline designs were prepared—one closely approximating to the turret ship proposed to be built, the other for a ship of the same dimensions and displacement, but with a continuous citadel. The same total weight was allowed in both designs for the protection above the belt armour—on the sides, round the turret-bases, and on the turrets. Except as regards the adoption of (1) a citadel, or (2) of redoubt and thin side armour, the ships were absolutely identical.

In the citadel ship, with the fixed total weight for protection, the thicknesses of armour found to be practicable were: On turrets, 15 in.; on citadel in wake of turrets, 14 in.; on sides of citadel (rising to 11 ft. above water), 12 in.

In the other design the practicable thicknesses were: On turrets, 18 in.; on redoubts (protecting turret bases), 17 in.; on broadside (rising to about 10 ft. above water), and on "screen bulkheads" (completing this thin armour across the ship), 4 in. to 5 in. That is to say, the latter design gave 3 in. greater protection to the stations of the heavy guns, at the cost of reducing the thickness of armour on the sides from 12 in. to 5 in., and lowering it about 1 ft. In the redoubt arrangement the 3-in. steel deck (as already explained) was situated at the level of the upper edge of the belt (3 ft. above water), and in the citadel arrangement, at the top of the citadel armour (about 11 ft. above water).

These and other facts having been placed before the naval officers attending the meeting convened by the First Lord, the following decisions were arrived at:—

"(*a*) That it was preferable to have two separate strongly protected stations for the four heavy guns, rather than to have a single citadel.

"(*b*) That on the whole the 4-in. armour amidships, from the belt deck to the main deck, associated as it would be with the internal coal bunkers, subdivided into numerous compartments, might be considered satisfactory; but that if armour weight became available, it could be profitably utilised in thickening the 4-in. steel above the middle portion of the belt."

I would draw particular attention to the first of these conclusions, since it expresses a most important distinction between the two systems of protection.

With separate redoubts, placed far apart, the two stations are isolated, and there is practically no risk of *simultaneous disablement* by the explosion of shells, or perforation of projectiles from the heaviest guns. Each redoubt offers a small target to the fire of an enemy, and its weakest part—the thick steel protective plating on the top—is of so small extent, that the chance of its being struck is extremely remote. Serious damage to the unarmoured turret bases, therefore, involves the perforation of the thick vertical armour on the redoubts.

With a single citadel, extending the full breadth of a ship, the case is widely different.

Over a comparatively large area of the protective deck-plating in the neighbourhood of each turret, perforation of the deck, or its disruption by shell explosions at any point, involves very serious risk of damage to the turret bases and the loading apparatus. In fact, such damage may be effected and the heavy guns put out of action while the thick vertical armour on the citadel is uninjured. Moreover, as the turrets stand at the ends of a single citadel, there is a possibility of their simultaneous disablement by the explosion of heavy shells within the citadel.

This last risk may be minimised (as in the *Nile* and *Trafalgar*) by constructing armoured "traverses" within the citadel; but it cannot be wholly overcome, so long as both turrets stand in one armoured enclosure.

It may be thought that the risk of damage to a 3-in. steel deck situated 11 ft. above water is remote; but I think the facts are as stated, when actions at sea are taken into account.

For example, if a ship of 70 to 75 ft. beam is rolling only to 10 degrees from the vertical, which is by no means a heavy roll, she presents a target having a vertical (projected) height of 13 to 14 ft. to an enemy's fire, and even if she is a steady, slow-moving ship, she will do this four or five times in each minute.

Now, at this angle of inclination, assuming the flight of projectiles to be practically horizontal, even the thickest protective steel decks yet fitted in battle-ships are liable to serious damage from the fire of guns of moderate calibre, and this danger is increased by the employment of high explosives. Of course I do not mean to say that this damage is to follow from fire intentionally aimed at the protective deck; but with a great and sustained volume of fire, such as is possible with a powerful auxiliary armament, and especially with quick-firing guns, it is obvious that there is a very real danger of chance shots injuring seriously the wide expanse of the protective deck at the top of a long citadel.

Again, it must be noted that the chances of damage to a deck placed 10 or 11 ft. above water, and with large exposed surfaces in the neighbourhood of the turrets when a ship is inclined or rolling, are greater far than those of a deck 7 or 8 ft. lower, and with 5-in. armour on the sides protecting the deck from the direct impact of shells containing heavy bursters. It is for the naval gunner to estimate these chances of injury; but, unless I am greatly mistaken, their verdict will be that a far greater number of shots are likely to strike at a height of 8 to 10 ft. above water than at a height of 4 to 5 ft.

These considerations I submit amply justify the selection of the separate redoubt system, in association with the thin side armour above the belt, and the lowering of the protective deck to the top of the belt in the new designs.

It may be urged that, if the redoubt system be adopted, it should be associated with side armour and screen bulkheads of greater thickness than 5-in. steel, and more strongly backed. This is perfectly practicable, but necessarily costly, involving an additional load of armour, and a corresponding increase in the size of the ship.

The Board of Admiralty, and the officers called into council, had in their possession, when considering this question, the most recent and complete experimental data, obtained by firing against the *Resistance*, with guns of various calibres (including quick-firers), projectiles of all patterns, and explosives of different kinds.

With this information in their possession, the Admiralty pronounce the thin armour above the belt to be "satisfactory," and give effect to that decision in the designs. Sir Edward Reed, in his letters to *The Times* and elsewhere, challenges this decision, and uses very strong language in its condemnation, but, so far as I am aware, he can have no experimental data to go upon, and his objections seem to rest on purely hypothetical assumptions of what kind and extent of damage is likely to happen to a ship, lightly armoured above the belt, when she comes under the fire of an enemy's guns.

Apart from any expression of personal opinion, I would submit that it is for the naval architect to prepare alternative plans, showing possible dispositions of the protective material, within the limits of weight available in a design. Having done this, it is not his province, but that of naval officers, to determine from their knowledge of gunnery, what are the nature and extent of the damages likely to be done in action, and to choose that disposition of the armour which they consider has the balance of advantage. This is the course which has been followed by the Admiralty in dealing with the disposition of the armour on the new designs.

From passages occurring in Sir Edward Reed's letters and elsewhere, it seems that he doubts whether the First Lord and his advisers, who made the selection, understood what they were doing. I leave it to these gentlemen to answer for themselves, if they think it necessary ; and anyone who will read through the Parliamentary papers will be able to judge whether any answer is required. I think that none is needed on the face of the published documents.

It is, I believe, a fair statement of Sir Edward Reed's views to say that his chief objection to the proposed arrangement of armour in the new designs, as compared with the *Trafalgar*, is that the *thick armour* on the side rises only 3 ft. above water,

instead of 11 ft. as designed for the *Trafalgar*, and about 10 ft. as completed. He speaks of "stripping a wall of armour 8 ft. high off the sides of the proposed battle-ships;" although in another place he is good enough to admit that the 5-in. armour which rises 9½ ft. above water is better than nothing, but it is a miserably inefficient substitute for the 18-in. armour, which (as compared with the *Nile* and *Trafalgar*) has been stripped off." And yet, again, he says:—"These ships are in principle, in so far as the defensive armour of the hull is concerned, neither more nor less than ships of the universally condemned *Admiral* class."

Taking the last statement first, I wish to challenge its accuracy, and to point out the essential differences between the *Admiral* class and the new designs, in the matter of "the defensive armour of the hull." In the *Admirals* the thick armour belt extends over about 40 to 45 per cent. of the length, as against 66 per cent. in the new ships. Above the belt, in the *Admirals*, cellular sides, extensive subdivision, and coal form the only protection; in the new ships these arrangements are supplemented by the long lightly armoured citadel above described, and the broadside is made secure against all the smaller natures of quick-firing guns, as well as against many of the most destructive projectiles from much larger guns, to a height of 9½ ft. above water — practically to the same height as the thick armour goes in the completed *Trafalgar*, and over as great a length amidships. Surely these are differences of the highest importance. They involve a very large expenditure of weight and money in the new ships, as compared with the *Admirals*, and add greatly to the defence. Yet they are practically ignored by Sir Edward Reed; whose condemnation of the proposed arrangements has regard almost exclusively to the fact that the thick armour is to rise only 3 ft. above water.

He objects to the adoption of *narrow water-line belts* of thick armour in battle ships generally, although I understand him to favour the use of such belts in cruisers. His contention, shortly stated, is that with such narrow belts there is a great risk that the damages done to the sides above the belt in action will speedily cause the ships to become unstable (in the transverse sense) and to reach a dangerous condition.

Now, clearly, this is a matter which turns chiefly, if not solely, upon the estimate that may be formed of the damage likely to be done in action. It is not a question of an abstruse nature, involving elaborate and scientific calculations of stability. Everyone can see that if a ship originally of high freeboard, carrying great weights of armament and armour aloft, could be brought down, by the rapid and wholesale destruction of her upper works, to a virtual freeboard of two to three feet (the height of the thick armour belt above water), while those great weights of guns and armour, &c., still remained aloft, she would reach a dangerous condition, and would be readily capsized. On this point there can be no difference of opinion. Moreover (as I pointed

out several years ago in a published correspondence with Sir Edward Reed), this element of danger, if it really exists, is not sensibly affected by carrying the narrow belt throughout the length instead of stopping short of the extremities.

Here then lies the pith of the whole question. Are such extensive damages likely to be done in action, and to be of a character that will virtually throw open to the sea the portions of the ships lying above the narrow armour belts? Is it to be regarded as impossible to keep ships thus armoured from capsizing under fire? What has been the general verdict of naval authorities on this matter, as evidenced in ships actually built?

Reference to the diagrams already used in connection with the dispositions of armament gives the answers to these questions. It will be seen that in the recent battle-ships of nearly all foreign navies belts of thick armour as narrow as, or narrower than, those condemned by Sir Edward Reed have been and are being adopted. Up to date, in most foreign ships, these narrow belts have not been associated with as effective a cellular construction of the sides as is possessed by the *Admirals* and other belted ships of the Royal Navy. Nor has coal protection been similarly cared for and made possible at the sides above the belts. Much less has there been provision hitherto in foreign ships of lightly armoured citadels above the belt, such as are proposed for the new ships. It is true that many of these foreign ships have belts going to the bow and stern; but that fact does not affect our present discussion, and it may be assumed, from what has been done and is doing abroad, that naval and professional authorities there, as well as at home, do not share the apprehensions expressed by Sir Edward Reed. By common consent his estimate of the serious risks inevitable with narrow belts is not endorsed.

On the next page I give a tabular statement showing the character of the water-line protection in a number of British and foreign ships, and the vertical distances to which the armour is carried above and below the designed load water-line.

It is perfectly obvious from this table that so far as the belt proper is concerned, the new ships are on practically the same footing as recent ships built in this country and abroad. But, I must repeat that they have above the belt a lightly armoured side, which most foreign ships have not. They are to be armoured, in fact, to 9½ ft. above water, as against 2½ to 3 ft. in most foreign ships; the total depth of armoured side is to be 15 ft., as against 7½ to 8½ ft. in some of the largest foreign ships. Relatively to those ships, therefore, the new designs clearly occupy a good position; and that is the true test.

In passing it will be noted from the diagrams that narrow belts have in nearly all cases been associated with dispositions of armaments placing the guns and their armour protection high above water and far apart.

I do not desire to enter into any lengthy explanation of the reasons which have led to this general adoption of narrow armour belts. Probably the chief reason is to be found in the fact that from the outset the depth to which armour has been carried *below water* has been very moderate.

	Armour as Designed.				Beam of Ship.	
	Depth of Belt below Load Water-Line.		Height of Thick Side Armour above Load Water-Line.			
	ft.	in.	ft.	in.	ft.	in.
Bellerophon	6	0	5	6	56	0
Hercules	6	0	8	6	59	0
Devastation	5	0	(4′ 2″ amidships and aft; 6″ forward)		62	3
Fury (design cancelled)	5	0	4′ 2″ amidships; 6″ forward.		62	3
Dreadnought	5	6	(11′ 0″ amidships; 3′ 0″ before and abaft citadel)		63	10
Inflexible	6 (7′ 0″ at fighting draught)	0	9 (8′ 8″ at fighting draught)	8	75	0
Trafalgar	5	6	(11′ 0″ amidships; 3′ 0″ before and abaft citadel)		73	0
New Designs	5	6	3	0	75	0
Amiral Duperré (French)	5	6	2	6	67	0
Amiral Baudin (French)	5	3	3	0	70	0
Magenta Class (French)	4	10	2	6	66	0
Sinope Class (Russian)	5	0	(11′ 0″ amidships; 3′ 0″ before and abaft base of battery)		69	0
Italia and Lepanto (Italian) ...	Armoured deck at side is 6 ft. below water as designed.				74	0
Duilio and Dandolo ,, ...	6	0	(10′ 0″ amidships; 2′ 0″ before and abaft base of citadel)		65	0

In recent years this depth has been somewhat diminished, as will be seen from the table, both absolutely and in relation to the beam of ships. Of course, it may be argued that the depth of armour below water ought to have been increased as ships

became larger and broader. That is a separate question, and just now we are concerned chiefly with matters of fact, and with comparisons of our ships with foreign ships. As a matter of fact, armour protection goes to a moderate depth below water in all cases. Consequently, it is quite possible, and in fact quite common, for the lower edge of the armour to be *emerged*, either by a very moderate inclination of the ship, or by her motion through still water, or by the movement of waves along her sides, or by her rolling in a seaway; as well as by many possible combinations of these circumstances. This emergence of the armour involves the exposure of the unprotected bottom, and chance shots entering below the armour may destroy the ship, and inevitably will cause damage that must be practically irremediable under the circumstances of action, and must result in the entry of large quantities of water into the vessel, even though she may be kept afloat by her water-tight subdivisions.

The unarmoured under-water portions of the sides and bottoms of war-ships are, moreover, exposed to serious damage in action by submarine torpedoes and by ramming; but it is unnecessary to dwell on the point.

Contrast with these undoubted risks, the risks involved in damage to the sides immediately above the armour belt, and also *above the normal water-line*. The consequences are clearly not so serious in many respects. Something may be done towards stopping or limiting the inflow of water when the damage is done above water. There is no head of water to deal with, as when the bottom below the armour is broken through. The projectiles which enter have opposed to them the protective deck at the top of the belt, and must pass through or seriously damage it before any of the vitals (boilers, engines, magazines, &c.) are attacked. And in the new ships (as already explained) projectiles must pass through the light armour before they can reach most portions of that deck—an immense advantage when high explosives are used.

Given, therefore, armour reaching to a moderate depth below water, a narrow belt is not such an unreasonable mode of protection as has been assumed, and the almost universal practice of adopting it is seen to have some justification.

I will only add one remark, which I feel disposed to apologise for, although it expresses a truth often overlooked in these discussions, viz., that the integrity of the unarmoured portions of a ship's bottom lying below the armour, is as essential to the maintenance of her stability as the integrity of the sides above the armour belt. Yet it is no exaggeration to say that very frequently when the gravest fears are expressed of what may result from damage to the out-of-water portions of ships, it is virtually assumed that the parts under water, when floating in still water, are not liable to injury in action. Such assumptions are clearly inadmissible.

This naturally leads me to deal with one illustration, avowedly couched "in simple language," which Sir Edward Reed has put before the public lately.

In his letter to *The Times*, above quoted, it is stated that the *Nile* could list over to about 17 degrees "before the top edge of the armour disappeared beneath the water;" while not a hint is given in any language, "simple" or otherwise, that under this assumed condition, the lower edge of armour on the other side of the ship would be about 5½ ft. out of the water, leaving 5½ ft. of unarmoured bottom exposed.

Other examples might be given of the one great fact apparent throughout Sir Edward Reed's utterances on this question of armour protection, viz., that there is no general or comprehensive survey and proportioning of the many risks that have to be encountered in action, but a restriction of the discussion to one, and that, by common consent, not the greatest risk.

Throughout his treatment of the new designs practically no regard is bestowed upon their "offensive" powers, and one might fairly say that the discussion proceeds as if the new ships were to be built chiefly with a view to make them efficient locomotive floating targets, capable of withstanding the effects of gun fire, and not capable of inflicting as well as receiving damage. To mention the point seems to me sufficient, without dwelling upon the incompleteness of this mode of treatment. In short, at least equal regard must be had to the provision of powers of offence as well as of defence in the determination of that compromise, which under existing conditions is the best disposal of the available capital in displacement and cost of any new type of war-ship.

Having made these general statements, I now wish to record my opinion that, in his haste to condemn the system of protection in the new designs, Sir Edward Reed has altogether failed to appreciate what would be involved in giving effect to his views.

I have shown that he has not recognised the great development of the auxiliary armament, and the influence of that development on the design generally; I have indicated the practical impossibility of effectively working that armament without placing it in a long central battery, and have pointed out the fact that with the citadel system and this long central battery, a very great increase in weight of armour, as well as size and cost of ship, must result.

Hereafter I shall deal with Sir Edward Reed's remarks on the supposed extravagant displacement of the new designs.

But for the moment, I simply wish to inquire if Sir Edward Reed, before writing in the terms he has employed, made any estimate of the increase in size and cost

which would be inevitable, if the same qualities, the same kind and disposition of armament, the same speed and coal endurance, were obtained in a vessel armoured as he suggests.

Of course Sir Edward Reed may consider that the armament is wrong in its character or badly disposed, and he may have had in his mind some ideal plan that, in his judgment, would be more satisfactory. If that be the case, he does not say so in his published letters or speeches, and the omission is to be regretted. But if he should have had such an alternative in his mind, then it must be stated that the issue as to armour protection is confused by introducing such modifications into the comparison. Moreover, it will not be universally admitted that on such questions as are involved in the character and disposition of armaments for battle-ships, the views of Sir Edward Reed are to be accepted in preference to those of the Admiralty and its naval advisers.

Description of the Barbette Design.

Although the foregoing descriptions have dealt chiefly with the turret ship design for a first-class battle-ship, in order that a comparison might be made step by step with the *Nile* and *Trafalgar*, it is proposed to build only one such ship out of the eight ships to be laid down.

This action is described as follows in the Parliamentary Papers :—

"Barbettes" *versus* "Turrets."—"The advantages and disadvantages of both systems having been reviewed, it was agreed (in view of the vessels existing in foreign navies or now under construction) that the barbette arrangement in design (*c*) was to be preferred in a battle-ship intended for general sea-going purposes. Sir Arthur Hood recommended that of the ships proposed to be laid down in 1889-90, in the dockyards, one should be on the turret system."

I will now proceed to summarise the chief points of difference between the designs (see Plates VIII. and IX.), to some of which allusion has already been made.

In the barbette ships the freeboard at the ends is increased to 18 ft., or $6\frac{3}{4}$ ft. more than the freeboard in the turret ship, and about 7 ft. 4 in. more than in the *Trafalgar* as completed.

The heavy guns are carried 23 ft. above water, as against 17 ft. in the new turret ship, and about 15 ft. as designed, or 14 ft. as completed, in the *Trafalgar*.

It is unnecessary for me to dwell upon the great advantages that should result from these changes in the power of maintaining speed and fighting guns in a seaway.

In the Royal Navy a very large proportion of our most recent and powerful ships are of moderate freeboard, carrying their guns only 12 to 14 ft. above water; whereas in foreign navies, in recent years, the heavy guns are chiefly carried from 22 to 28 ft. above water, and the freeboard is high.

The decision of the Admiralty to largely adopt the barbette design is avowedly based on these facts, and arrived at with a full knowledge of the relative advantages and disadvantages of the turret and barbette systems, after considering designs for turret ships with guns placed at equal height above water, and with the same freeboard as the barbette ship.

It will be obvious that the increase in height of freeboard and of guns above water can only be secured by means of additional hull-weights, and re-arrangements of the armour. What has been done is this: the turrets have been abolished, and the weight of armour, &c., utilised in adding to the height of the redoubts in which the turret bases stand. The barbettes thus formed are strongly armoured from the 3-inch protective deck above the belt upwards, and are divided into two stories. In the upper story stand the turntables carrying the heavy guns, in the lower story will be placed the turning engines and other important portions of the equipment.

In most barbette ships hitherto built, whether English or foreign, the barbettes have been shallow armoured cylinders with plated bottoms, standing on light steel structures at a considerable height above the belt deck. Armoured tubes have been fitted to protect the ammunition when it is passed up from the magazines into the barbettes.

This system greatly economises weight of armour, but the development of high explosives makes it possible that shells containing bursting charges of great energy might be exploded immediately under the floors of the barbettes. Consequently it has been decided in the new ships to adopt the alternative system, above described, although it involves a very large expenditure of weight and cost on armour.

The hydraulic system of mounting, working, and loading the 67-ton barbette guns to be carried out in the new ships will resemble closely that already successfully adopted in the *Admiral* class.

As regards the disposition of the belt armour, protective deck, and 5-in. armour, as well as the protection of the auxiliary armaments, the barbette ships are identical with the turret design, already described.

Speed.

It was originally contemplated to adhere in the new designs to the speed that had been first accepted for the *Trafalgar*, viz., 15 knots on the measured mile, with

natural draught, and 16½ knots with forced draught. In working out the designs, it has been found possible to increase these speeds to about 16 knots natural draught, and 17½ knots with forced draught.

These estimates of speed are, of course, based upon model experiments made in the Admiralty establishment at Haslar, by Mr. R. E. Froude, and upon our analysis of the results of speed trials of recent ships. It was with some surprise, therefore, that I found this estimate questioned by Sir E. Reed in the following passage, in his letter published in *The Times* of March 22 :—

"There is a slight alleged increase of speed, ½ a knot." "This assumed increase of speed is, however, fallacious, because, as a matter of fact, the *Nile* and *Trafalgar*, having 12,000-horse power to drive 12,000 tons of ship, will obviously have the advantage in speed of ships which have but 13,000-horse power to drive 14,000 tons of ship."

This kind of criticism is so extremely popular in its form that I am almost disposed to apologise to the Institution for explaining why we may reasonably anticipate a higher speed in the new ships, apart from the practical certitude obtained by means of the model experiments and trials of other ships.

The new ships are to be 380 feet in length, as compared with 345 feet for the *Trafalgar*. They will be 14,150 tons displacement, as against 12,000 for the *Trafalgar* as designed, and 12,500 tons for that ship as completed. Our model experiments show that, for speeds from 10 knots up to 16 knots, the resistances of the two forms are, for all practical purposes, equal; the greater length of the new ships compensating for their greater displacement.

But at speeds higher than 16 knots the longer form begins to gain sensibly on the *Trafalgar*, and at 17 knots the *Trafalgar* form would require about 12 per cent. greater power than the new ships. At 17½ knots the *Trafalgar* form, if it could be driven, would require at least 30 per cent. greater power than the heavier but longer ships. Now this speed of 17½ knots is what is estimated as the maximum (forced draught) performance with 13,000-horse power in the new ships; while with 9,000-horse power (natural draught) we hope to reach about 16 knots.

The *Trafalgar's* specified powers are 8,000-horse power natural draught and 12,000 horse power forced draught; and I am happy to be able to say that on the measured mile these powers ought to give her speeds of about 15½ knots and 16¾ knots respectively.

Put in another way the facts are these.

The *Trafalgar* form is well adapted for the maximum speed intended in the design,

16½ knots; it is not well adapted for higher speeds, and even if large additional power could be developed, very little extra speed would be gained. On the other hand, the greater length of the new designs renders them suitable for speeds up to and beyond 17½ knots, and if additional power were developed the gain in speed would be appreciable.

I must refer to another passage in Sir Edward Reed's letter before passing on; it runs as follows:—

"If the increase of size given to them (the new ships), and the increased cost to be bestowed upon them, were to be judiciously applied by competent persons, the result would be ships having a speed of 20 knots, with a coal supply far beyond that which these ships are to possess. Considering how cheaply speed is now obtained, I cannot myself deny that I should like to see our great ships able easily to overtake any enemy's fleet."

I pass by for the present the allusion to "competent persons," and wish to direct attention to the statement made as to the possible increase in speed. Taking the passage as it stands, I find no allusion to any diminution in armament; the letter, as has been shown, recommends no decrease in armour protection or coal supply, but the reverse; and yet these grand results are alleged to be possible without increase of size.

I do not desire to make this discussion and criticism a personal matter; but I may be permitted to mention that my professional work in recent years has given me a somewhat intimate acquaintance with what is involved in the attainment of high speeds. Nor do I consider that we are at the end of the remarkable progress in marine engineering which has facilitated, or rather I should say has rendered possible, recent advances. On the contrary, I recognise many promising methods of getting greater power in relation to weight as likely to influence further practice, and no one will welcome them more heartily than I.

We are considering at present, however, the case of great battle-ships to be built immediately wherein experiments in engineering are clearly undesirable, and where the certain possession of endurance as well as maximum speed is of primary importance. And apart from this fact, I entirely challenge the statement that when speeds of 17 to 20 knots are in question for battle-ships, even of the largest size, increase in speed is to be "cheaply obtained." Experience and experiments are contrary to such an assertion, and the onus of proving it to be true lies on the person who makes it.

Figures might be multiplied to show that my contention is correct; but I will only give two illustrations. In the new battle-ships it requires the horse-power to be doubled in order to pass from 14 knots to 17 knots; but a further doubling of the power would not add another 2 knots. This will scarcely be thought a "cheap" increase of speed.

In the mercantile marine, speeds of 20 knots are being attained in steamers of 12,000 to 13,000 tons' load displacement and 26 ft. draught, but 500 to 560 ft. in length, and having a ratio of beam to draught and length which is altogether inadmissible for a war-ship carrying heavy weights of armour and armament high above water. But even under these conditions speed is not "cheaply" increased from high speeds such as 17 knots to the still higher speed of 20 knots. To take an actual case within my knowledge, the ratio of the power at 20 knots to that at 17 knots was found to be 2 to 1.

In illustrating the truism that great expenditure of power is inevitable when such a speed as 20 knots is obtained, I do not assert that battle-ships may not be produced having that speed. What I challenge is the statement of Sir Edward Reed that in ships of the size and cost of the new battle-ships "competent persons" could produce ships as heavily armed, more heavily armoured, "having a speed of 20 knots, with a coal supply far beyond that which these ships possess." That statement could not have been made if he had given even the most moderate amount of consideration to the enormous power and weight of machinery necessarily required to obtain 20 knots with any possible form of ship; to the serious difficulties involved in providing space for the accommodation of the propelling machinery, boilers, and coal, as well as magazines, store-rooms, &c., under protection in the hold; and to the fact that the maximum draught of water being necessarily a fixed quantity, changes of form, in length especially, and increase in weights of hull and armour, would be unavoidable. All these points are matters of fact, not of opinion. They lie on the very surface of the problem, and they obviously require to be dealt with in a careful scientific manner, not in an airy general style, taking for its basis the idea that speed is now "cheaply obtained."

Before leaving this question of speed, it may be well to point out the fact that these new battle-ships will possess speeds exceeding those of nearly all battle-ships built or building. They will form a squadron of identical character and qualities, capable of proceeding and manœuvring together. Taken as a group, they will certainly be "able easily to overtake any enemy's fleet." And what is equally important, they will, under the new programme, be associated with a number of very swift cruisers and torpedo gunboats, thus constituting a force complete in all respects, and of unrivalled power as well as speed.

Coal Supply and Endurance.

It was decided, after full consideration, that the new ships should ordinarily carry 900 tons of coal, as in the *Trafalgar;* and be capable of covering the same distance, viz., about 5,000 knots at 10 knots.

Like the *Trafalgar*, the new ships will have a bunker capacity sufficient to carry a much larger quantity of coal if desired.

But whereas any increase above 900 tons in the coal put on board the *Trafalgar* necessitates an increased draught and some loss of speed, in the new designs provision is made (in the form of the so-called "Board Margin") for an unappropriated weight exceeding 500 tons to be carried at the designed load draught and at the full speed.

Strictly speaking, therefore, the case stands thus :—

Trafalgar—coal at load draught, 900 tons.
New designs—coal at load draught and unappropriated weight, about 1,400 tons.

If the unappropriated weight should be assigned to coal, it would give the new designs a coal endurance of nearly 8,000 knots at 10 knots.

Apart from any such increase in coal, however, the 900 tons proposed is a very large supply in relation to expenditure ; larger, in fact, than that of nearly all first-class battle-ships. Take for example the *Thunderer* and *Devastation* as completed. They can cover about 4,700 knots at 10 knots. Their full speed for continuous steaming in smooth water is estimated at 12½ knots, at which speed they can cover about 2,700 knots. At that speed with 900 tons of coal the new ships could cover about 3,500 knots. At the highest speed contemplated for smooth water, continuous steaming—about 16 knots—the new ships could cover about 1,900 knots. The forced draught speed is never intended to be maintained for more than four to five hours continuously ; so that an estimate of coal endurance under these conditions is worthless for any practical purpose.

There is one class of ships in the Royal Navy (the *Admirals*) which has an unrivalled coal endurance, and one ship in that class, the *Collingwood*, which surpasses the others. This vessel (the *Collingwood*) is selected by Sir Edward Reed as a standard of comparison on which to base a hostile criticism in dealing with the coal capacity of the new ships. Nor is this all, as the following passage will show. He says :—

"When the *Collingwood* was designed, she was provided with engines of 7,000-horse power, and a coal supply of 950 tons. The proposed new ships are to have 13,000-horse power, and in the same proportion should carry 1,760 tons of coal ; but, incredible as it may seem, 900 tons of coal is all that is to be allowed them."

It will be sufficient to indicate in the briefest fashion the misleading character of the comparison here made.

(1) The 7,000-*horse power* mentioned for the *Collingwood* was with *natural*

draught; the 13,000-*horse power* for the new ships is with *forced draught*, their natural draught power being 9,000-horse power.

(2) The new ships will have triple expansion engines, which may be assumed to be at least 15 per cent. more economical in coal consumption than the compound engines fitted in the *Collingwood.*

(3) The *Collingwood* can steam about 7,000 knots at 10 knots, if she starts with 900 tons of coal, her full authorised quantity. The new ships with the same weight of coal will steam 5,000 knots at 10 knots: to cover 7,000 knots they would have to start with about 1,250 tons of coal, or 350 tons more than the ordinary supply of 900 tons. This 350 tons is (as explained above) less by more than 150 tons than the unappropriated Board Margin which has to be carried at the load draught and full speed in the new ships.

The coal endurance of H.M. ships has to be regulated by other considerations than those of mere comparison with the corresponding feature in foreign ships. To this point I referred at length in the discussion on Sir N. Barnaby's paper on "Fuel Supply," published in the Transactions for 1887. But it may be interesting to state that no foreign war-ships, except, perhaps, the *Italia* and *Lepanto*, have coal endurances approaching those of the new designs. And further, it must be remarked that published statements of coal endurance for foreign ships are frequently based upon mere bunker capacity, and not upon the coal carried at the reputed load-draughts and full speeds.

Remarks on the Size of New Battle-ships.

In conclusion, I desire to make a few remarks on the criticisms that have appeared with reference to the very large size and displacement of the new battle-ships.

These criticisms may be arranged in two groups.

First: What may be termed the "too many eggs in one basket" class of objection.

Secondly: Those which allege that the ships have been made unnecessarily large in relation to the qualities of speed, coal endurance, armament, and protection they are intended to combine.

The first class are criticisms of the policy represented in the designs, and these I shall leave unanswered, since the Board of Admiralty are responsible for that policy, and I am their technical adviser. But it will be noted that the procedure followed in deciding on the designs involved a selection from amongst a number of alternatives representing ships of various classes, sizes, and costs.

Independently of actual experience in a great naval war, and the experimental demonstration of the relative advantages and disadvantages of a group of smaller ships, as against a less numerous squadron of ships individually more powerful—the aggregate outlay in each case being the same—the choice between the two policies of construction must be largely a matter of opinion. But I presume it will be admitted that the Admiralty and its naval advisers constitute as competent a body as can be found to deal with such matters.

Moreover, it must be noted that in the existing fleet we already have large numbers of battle-ships of less size and cost than the projected vessels; and that the new programme associates with the eight first-class battle-ships, two second-class battle-ships of moderate size, and a very large number of swift cruisers. So that, taking the fleet as a whole, all views may be considered to be represented.

The second class of criticism is one that peculiarly concerns myself as the responsible designer of the ships; for it really amounts to a charge of professional incompetency. If these ships have been made larger and more costly than was necessary to secure the combination of qualities decided on by the Board of Admiralty, then I, primarily, and my colleagues and assistants in the constructive and engineering department of the Admiralty are clearly to blame.

Sir Edward Reed has made this charge of "incompetency" in unmistakable language in the passage above quoted when dealing with speed.

And further on in his letter he states—"The day for getting the best possible ships out of our Whitehall office is past and gone."

It would have been interesting if he had fixed the date from which this decadence in the "Whitehall office" began; but that is not done in the letter from which I have quoted.

In dealing with this serious allegation, I desire, however, to sink all personal feeling, and to disregard the attack made on the "competency" of the Admiralty professional officers. My intention is to put a plain statement of facts before the Institution, and to allow the facts to speak for themselves. Fortunately, my task is easier, because Sir Edward Reed has himself requested that the "comparison which he has set up between the *Nile* and *Trafalgar*, and the proposed ships," may be tested; and this I will now proceed to do. To make the comparison as precise as possible, I will take the new turret ship design, and, to make it complete in this place, I will repeat some figures already given.

On the tabular statement for the various classes of battle-ships appended to this paper, the principal particulars for the *Trafalgar* (as *designed*) and for the new ships are compared.

Originally the *Trafalgar* was intended to have a load displacement of 12,000 tons, and a mean load draught of 27½ feet, trimming one foot by the stern, with 900 tons of coal on board.

It is explained, however, in the Parliamentary Papers, that owing to various additions made during construction and to other causes, the completed *Trafalgar* will be 500 tons heavier, and draw about 10 in. more than designed. For purposes of comparison, therefore, she must be taken as a vessel of 12,500 tons, having a mean draught of nearly 28½ ft., and an extreme draught aft of 29 ft., with 900 tons of coal on board. When she fills up her bunkers to 1,200 tons she will draw about 6 in. more.

Here then we have the true starting point in the comparison with the new ships: a vessel of 12,500 tons drawing 28½ ft. mean and 29 ft. extreme.

With these facts before them, the Admiralty decided that in the new designs the original mean draught intended for the *Trafalgar* (viz., 27½ ft.) should not be exceeded; and this decision is set out in the Parliamentary Papers.

Before this Institution it is scarcely necessary for me to dwell upon the great influence which this decision to keep to a draught shallower by one foot than the actual draught of the *Trafalgar* must have had on the new designs. But Sir Edward Reed, although himself a naval architect, ignores the detailed statement of facts in the Parliamentary Papers, and makes no allusion to the consequences.

I will very briefly correct his omission, and state what the change in size would be if the *Trafalgar* were re-designed to float at the 27½ ft. mean draught, carrying the same armament, the same equipment, the same armour protection, and to steam at the same speed as the actual *Trafalgar*. To fulfil these conditions would involve an extra length of about 20 ft., and would require a displacement of about 13,000 tons.

Keeping these figures in mind let us turn to the new ships, which are to be 380 feet long, of 14,150 tons displacement, and 27½ feet mean draught.

They are consequently of 1,650 tons greater displacement than the *Trafalgar* as completed, but of 1 ft. less draught. They are of about 1,100 to 1,200 tons greater displacement than the re-designed *Trafalgar* floating at the same draught would be.

Now let us see how this difference in displacement (1,100 to 1,200 tons) is made up; and here the ground has been cleared by some of the statements made in the preceding pages.

The following are (in round figures) the excesses *in loads to be carried in the new ships*, quite independent of increase in size :—

Auxiliary Armament...	300 tons.
Increased Complement, &c.	60 ,,
Board Margin of Weight (equivalent to enlarged Coal Supply)	520 ,,
Weight of Armour, &c., to lift Turret Guns two feet higher above water than in *Trafalgar*	150 ,,
Total increase in load	1,030 ,,

To carry this heavier load on the same draught (27½ feet) as the re-designed *Trafalgar* necessarily requires a longer and larger ship, and therefore a heavier hull. Furthermore, in the new ships, as explained above, machinery of greater power than that in the *Trafalgar* is to be provided, not for the purpose of driving the larger ships as fast as the *Trafalgar*, but to obtain an absolutely higher speed, the difference in speed being at least half a knot, and possibly more, in favour of the new ships.

The foregoing statement of facts will probably be found sufficient by members of the Institution to explain the increase in size of the new ships; and to illustrate the statement which I will now add. They have not been made any longer or larger than is absolutely necessary—under existing conditions of naval architecture and marine engineering—to fulfil the conditions laid down by the Board.

My friend and colleague Mr. Sennett and I are perfectly acquainted with the savings in weight or equivalent increase in power and speed which would be possible if we had adopted certain new types of boilers or novel arrangements of machinery which have undergone limited trials with considerable success.

We are, moreover, most favourably disposed towards the gradual developments of all systems which promise such beneficial results. But we do not consider it wise or right to make such experimental trials on ships of the magnitude and importance of these new battle-ships. And after the fullest consideration our advice to the Board has been to adhere to arrangements with which we have experience, and of which the success is assured.

Before sitting down I will add two or three statements which appear to be of some importance when dealing with the relatively large size of the new ships.

First: They have been shown to be made large by the great *loads* of armament, equipment, and Board Margin they carry on a moderate draught at high speed.

Omitting the Board Margin (or allowance for contingent additions during construc-

tion) the ships are of 13,600 tons displacement, and about 26 feet 8 inches mean load draught. These are the figures strictly comparable with the other ships: using them the following table is instructive.

	Length.		Mean Draught.		Displacement.	Maximum Speed.
	ft.	in.	ft.	in.	Tons.	Knots per hour.
New Ships (excluding Board Margin)	380	0	26	8	13,600	17·5
Trafalgar (as designed)	345	0	27	6	12,000	16·5
Inflexible	320	0	25	3	11,880	13·8
Dreadnought	320	0	26	9	10,820	14·2
Minotaur	400	0	26	9	10,690	14·4
Warrior	380	0	26	9	9,210	14·1
			Extreme Draught.			
Italia	400	6	31	3	13,900	18
Lepanto	400	6	30	9	13,550	18
Sicilia	400	0	28	6	13,253	18
Amiral Baudin	321	6	26	2	11,380	15

Second: The new ships, although of a displacement surpassing all previous battle-ships, are certain to be much more manageable than many of their predecessors with equal or greater length, and not possessing twin screws.

Lastly, it will be seen that since the increase in size is chiefly due to increase in load, the assumptions that have been made by Sir Edward Reed and others as to relative increase in cost are not well founded. I am not at liberty to make any statement respecting the Admiralty estimate of cost for these ships, for reasons which will be obvious. But this I may say, that while the total weight of protective material in the new ships is greater than the corresponding total in the *Trafalgar* by something like 150 tons, the adoption of the 5-in. armour in association with redoubts, instead of a central citadel thickly armoured throughout, has the result of largely reducing the cost of the armour. This was not the reason, however, for the adoption of the system, as has already been explained. At the next meetings of the Institution this question of cost may be debated on the basis of ascertained figures, and I therefore say no more.

The paper has extended to an unusual length, yet I venture to believe that this has been warranted by the importance and range of the subjects treated. It has unavoidably assumed a controversial character in certain parts; but I am not responsible for the circumstances, and I trust that nothing has been said by me which goes beyond fair reply or criticism. I have, in fact, been put upon my defence as a naval architect who holds a position of some public importance, and who should clearly cease to occupy that position if the allegations of incompetency that have been made so freely and publicly could be sustained. But beyond any personal interest in the matter, I appear here as the representative and head of the Constructive Department of the Admiralty—the "Whitehall Office," which is said to be no longer capable of producing "the best possible ships." Apart from the fact that I am the head of that staff, and apart from any question of my personal competence, I desire to state that there never has been a time during my experience of the Admiralty Office—an experience extending over twenty-two years—when the members of that staff included so many thoroughly educated, capable, and qualified naval architects and marine engineers as are now serving there. The great system of technical education, established by the Admiralty twenty-five years ago, largely in consequence of the recommendations of this Institution, has borne good fruit, and the Public Service is reaping the benefit, not merely at the Admiralty, but in the Dockyards; while, outside the service, men similarly trained have risen to the highest professional eminence.

If with such a staff, with all our recorded data and experience, with our grand experimental establishment at Haslar, so ably conducted by my friend Mr. Froude, and with all the valuable assistance and suggestions coming to us from the Naval Service, and our professional colleagues in the Dockyards, as well as the constant benefits we derive from a full knowledge of the work done by private shipbuilders and foreign competitors, we do not, in the "Whitehall Office," succeed in producing "the best possible ships" consistent with the instructions of the Board of Admiralty, then there can be no excuse. But I contend that the allegations made against the professional officers of the Admiralty have been loosely made, and are proved to be unfounded, as regards the designs of the new battle-ships, by the facts which have been adduced.

A much more important question than that of our professional competency arises from the discussion; and public interest must chiefly centre in it, since it seriously affects the national defence. Assuming that we have done the best that could be done under instructions received from the Board of Admiralty, the country desires to know whether the ships proposed to be built are "the best possible ships" which can be added to the Navy under existing conditions of naval warfare.

On this question I shall not be expected to give an opinion. It involves an inquiry into the competency of the Board of Admiralty and our system of naval administration. But at the risk of repeating statements already made, I must say that there never have been designs more deliberately and carefully considered. The selection was made from amongst a large number of alternative designs, after a careful review of what is being done abroad, and with reference to various proposals not yet embodied in actual ships. Fortunately, it could be based upon a great mass of new experimental data, obtained by actual trials against the *Resistance* and elsewhere, and giving the latest and best information in relation to guns, projectiles, explosives, and armour. Moreover, the Board of Admiralty has availed itself of the advice and assistance of a number of distinguished officers before coming to a decision.

A complete account of the action taken, and the reasons for the various conclusions reached, has been placed before the public. Obviously there is room for differences of opinion, since actual experience in naval warfare under modern conditions is almost entirely wanting. The matter, therefore, resolves itself into one of *relative authority and experimental information*. Under these circumstances, the Naval Service and the country will probably prefer to accept the conclusions of a responsible and well-informed body like the Board of Admiralty, rather than those of any individual.

DISCUSSION.

Sir Edward Reed, K.C.B., F.R.S., M.P. (Vice-President): My Lord Ravensworth, my Lords and gentlemen, the concluding remarks of my friend Mr. White have gone very far, in my judgment, to explain the harder and harsher parts of my criticisms, because he there points out that the practical issue involved as to the production of designs is an inquiry into the method in which all these matters are dealt with by the Board of Admiralty; and I would like, at the outset, in order to relieve the debate as far as possible from personal feeling, to say that it has been with immense regret that on the recent, or any other occasion, I have had to say or do anything casting reflections on my fellow professional men, but that I am encouraged by the knowledge of the fact that if I had not been doing so for a long series of years, we should be having very different ships built for the Navy at the present moment than those which are now before the Institution. My Lord, I should like to explain, if I may be allowed, that although Mr. White was courteous enough to furnish me as early as possible with a copy of his paper—I believe one reached my office yesterday in the middle of the day—it did not come into my hands until last evening at the House of Commons, and I was not able before arriving home at half-past one this morning from Parliament to read a line of it, so that what I have to say on the paper must be regarded as unpremeditated. I will endeavour, my Lord, to be as pointed as possible, and to keep as close to the paper as possible, and I hope my remarks will be treated by the meeting with the consideration which is due to one who has to speak under such circumstances of pressure as to time. I should like to say also, my Lord, that I take no objection whatever (and I am very glad to say so) to any part of Mr. White's paper, or to the tone in which it is couched. I think that he has been very fair and moderate, considering the nature of the attacks to which I, more or less intentionally and more or less directly, have subjected him, and I am glad to

ERDOWN and SON. As completed.	SACHSEN.	DUILIO.	AMIRAL DUPERRÉ.	MAGENTA CLASS.	ITALIA and LEPANTO.	SINOPE CLASS.
1888	1877	1872	1876	1881	1877	1883
	German	Italian	French	French	Italian	Russian
330 0	298 0	332 0	311 0	323 0	400 6	300 0
68 6	60 0	64 9	66 11	65 7	72 9	69 0
28 0	....	26 7*	26 9*	27 3*	31 3*	26 0*
10,650	7,400	11,138	11,100	10,580	13,900	10,800
10 3	....	....	....	....	....	....
10 3	....	....	....	....	....	....
....	5,600	10,000	5,780	7,000	18,000	....
11,000	....	....	8,000	....	....	13,000
....	14·0	15·0	....	....	....	....
16·8	....	....	14·2	15·0	18·0	16·8
900	700†	1,279†	....	600	1,650†	886†
6,000	Not known accurately.					
4—67 ton B.L.	6—18 ton B.L.	4—100 ton M.L.	4—47 ton B.L.	4—52 ton B.L.	4—100 ton B.L.	6—50 ton B.L.
6—6 in. B.L. 19 { 6 prs. Q.F. 3 prs. Q.F.	4—15 prs.	1—33 pr. 4—3 in. B.L.	1—6 in. B.L. 14—5½ in. B.L.	17—5½ in. B.L.	8—6 in. B.L.	7—6 in. B.L.
1,250	412	2,002	926	926	2,002	732
630	126	507	258	357	661	247
1,070	....	....	....	....	....	....
200	....	....	....	....	....	....
19 9	....	....	....	....	....	....
150 0	....	....	....	....	....	....
18	16	21½	21½	18	....	16
3	....	....	3	3	3¼	3
1,210	....	....	....	....	....	....
3,130	....	....	....	....	....	....

Nᴏᴛᴇ.—These particulars are chiefly taken from Lord Brassey's "Annual."

* These are extreme draughts.

† These are believed to represent the bunker capacity, and not the amounts carried on the draughts given.

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PARTICULARS OF BRITISH AND FOREIGN BATTLE SHIPS.

	New Designs.		TRAFALGAR.	SULTAN.	DEVASTATION.		FURY.	DREAD-NOUGHT.	INFLEXIBLE.	COLLINGWOOD.		CAMPERDOWN and ANSON.		SACHSEN.	DUILIO.	AMIRAL DUPERRÉ.	MAGENTA class.	ITALIA and LEPANTO.	SINOPE class.
	Turret Ship.	Barbette Ship.	As designed.	As designed.	As designed.	As completed.	As designed.			As designed.	As completed.	As designed.	As completed.						
Date of Design	1889		1885	1868	1869	1873	1870	1872	1874	1880	1886	1882	1888	1877	1872	1876	1881	1877	1883
Name of Designer	Mr. W. H. White		Mr. Barnes Mr. Morgan	Sir Edward Reed.						Sir Nathaniel Barnaby.				German	Italian	French	French	Italian	Russian
Length ..... feet	380 0		345 0	325 0	285 0		320 0	320 0	320 0	325 0	325 0	330 0	330 0	298 0	332 0	311 0	323 0	400 6	300 0
Breadth ..... ,,	75 0		73 0	59 0	62 3		62 3	63 10	75 0	68 0	68 0	68 6	68 6	60 0	64 9	66 11	65 7	72 9	69 0
Draught (mean) ..... ,,	27 6		27 6	25 0	26 2	26 8	26 2	26 9	25 4	25 9	26 4	26 9	28 0	....	26 7*	26 9*	27 3*	31 3*	26 0*
Displacement ..... tons	14,150		*12,000	†8,700	9,060	9,300	10,460	10,900	11,880	9,200	9,500	10,025	10,650	7,400	11,138	11,100	10,580	13,900	10,800
Freeboard .... Forward ..... feet	11 3	19 6	11 3	19 8	9 3	8 6	10 4	10 9	9 6	12 6	11 11	11 6	10 3	....	....	....	....	....	....
Freeboard .... Aft ..... ,,	11 3	18 0	11 3	17 9	5 0	4 6	5 6	10 0	9 6	11 6	10 11	11 6	10 3	....	....	....	....	....	....
I.H.P. ..... Natural draught	9,000		8,000	7,200	5,600	6,600	7,000	8,000	8,000	7,000	....	....	....	5,600	10,000	5,780	7,000	18,000	....
I.H.P. ..... Forced ,, ...	13,000		12,000	....	....	....	....	....	....	....	9,500	9,500	11,000	....	....	8,000	....	....	13,000
Speed ..... Natural ,, knots	16·0		15·0	14·0	12·5	13·8	13·5	14·0	13·8	15·0	....	....	....	14·0	15·0	....	....	....	....
Speed ..... Forced ,, ,,	17·5		16·5	....	....	....	....	....	....	....	16·5	16·0	16·8	....	....	14·2	15·0	18·0	16·8
Coals carried at the designed load draught ..... tons	900		900	600	1,700	1,350	1,600	1,200	1,200	950	900	900	900	700†	1,279†	....	600	1,650†	886†
Coal endurance at 10 knots..... knots	5,000		5 000	1,700	4,300	4,700	4,000	5,700	4,200	7,300	7,000	....	6,000	Not known accurately.					
Armament .... Main	4—67 ton B.L.		4—67 ton B.L.	8—18 ton M.L. 3—12½ ton M.L. 2— 6½ ton M.L.	4—25 ton M.L.	4—35 ton M.L.	4—35 ton M.L.	4—38 ton M.L.	4—80 ton M.L.	4—43 ton B.L.	4—45 ton B.L.	4—63 ton B.L.	4—67 ton B.L.	6—18 ton B.L.	4—100 ton M.L.	4—47 ton B.L.	4—52 ton B.L.	4—100 ton B.L.	6—50 ton B.L.
Armament .... Auxiliary	10—6 in. Q.F. 18 { 6 prs. Q.F. 3 prs. Q.F.	10—6 in. Q.F. 24 { 6 prs. Q.F. 3 prs. Q.F.	8—5 in. B.L. 18 { 6 prs. Q.F. 3 prs. Q.F.	16—24 prs. Howitzers	Boat and Field Guns only.				8—20 prs.	6—6 in. B.L.	6—6 in. B.L. 12—6 prs. Q.F.	6—6 in. B.L.	6—6 in. B.L. 19 { 6 prs. Q.F. 3 prs. Q.F.	4—15 prs.	1—33 pr. 4—3 in. B.L.	1—6 in. B.L. 14—5½ in. B.L.	17—5½ in. B.L.	8—6 in. B.L.	7—6 in. B.L.
Weight of Projectile (heaviest) .... lbs.	1,250		1,250	410	548	714	714	820	1,700	714	714	1,250	1,250	412	2,002	926	926	2,002	732
Weight of Charge ..... ,,	630		†520	70	85	140	140	180	450	315	295	520	630	126	507	258	357	661	247
Total Weight of Armament..... tons	1,420	1,410	1,035	560	355	515	515	525	920	660	760	960	1,070	....	....	....	....	....	....
Weight of Auxiliary Armament .... ,,	480	500	135	22	....	....	....	....	....	120	200	160	200	....	....	....	....	....	....
Height of centre of metal of heavy guns above designed water-line ..... feet	17 0	23 0	15 0	13 6	14 9	14 3	15 6	15 6	13 6	21 6	20 11	21 0	19 9	....	....	....	....	....	....
Length of Belt ..... ,,	250 0		230 0	Whole length	Whole length	Whole length	Whole length	Whole length	110	140 0	140 0	150 0	150 0	....	....	....	....	....	....
Greatest thickness Side armour .. ins.	18		20	9	12	12	12	14	24	18	18	18	18	16	21½	21½	18	....	16
Greatest thickness Protective Deck ,,	3		3	....	3	3	3	3	3	2½	2½	3	3	....	....	3	3	3½	3
Weight of Horizontal Armour Deck, Glacis Plates, &c. ..... tons	1,100		1,040	....	415	556	600	680	970	905	940	1,140	1,210	....	....	....	....	....	....
Total weight of Armour and Backing, including Protective Deck ..... ,,	4,550		4,400	1,800	2,700	2,900	3,330	3,690	3,540	2,730	2,780	3,150	3,130	....	....	....	....	....	....
			* Displacement, when complete, will be 12,500 tons. † Now 630.	† Displacement, as completed, about 9,300 tons, including 460 tons of ballast.		See Plate XI. as to superstructures and armoured bulkheads added during construction. See also page 8 of "Transactions," I.N.A., for 1873.	Work stopped early in 1871, and design cancelled.		Figures above relate to armament actually carried. Lighter turret guns were originally proposed.	See Parliamentary Paper, No. 222, of 1887.		See Parliamentary Paper, No. 237, of 1888.						

Note.—These particulars are chiefly taken from Lord Brassey's "Annual."

* These are extreme draughts.

† These are believed to represent the bunker capacity, and not the amounts carried on the draughts given.

see that he has not made this the occasion of aggravating any of the differences that exist between us on these matters. Now, my Lord, the first point that I should like to refer to—and the meeting will excuse me for going lightly over what I regard as incidental matters—is, that there is a certain mystery which nothing that has been said in the Parliamentary papers, and nothing which has been said in Mr. White's paper, has cleared up; a mystery attaching to the part which Naval officers outside the Admiralty have taken in connection with these designs. Mr. White's own statement, if he will allow me to say so, is rather peculiar. He says, "The choice eventually made by the Board was made from among a considerable number of alternative designs, and before coming to the design the first Lord convened a meeting." That is pretty much to the effect of what the Parliamentary papers say, only as I read the Parliamentary papers (and there are gallant gentlemen present who will be able to put this right later in the debate if I am wrong) the course taken was this; that the Naval gentlemen of whom the Admiralty took counsel at Devonport were consulted as to certain matters, and the question as to which their opinion—perhaps rightly, but in my opinion most wrongly—was in the first place taken was the nature of the armament, and the disposition and placing of the armament. Now, my Lord, I, for one, close at once with the doctrine that in building a first-class battle-ship for this country armament considerations ought to take a first place. I may be entirely wrong. It may be that the importance I attach to keeping a ship or a series of ships (which cost a million of money apiece, carrying many lives) afloat is excessive; but to my mind, not when you are dealing with cruisers, or ships of secondary importance, but when you are dealing with a line-of-battle ship to go out into the Channel and destroy the enemy, and to protect our coasts, the first consideration I think should be that that ship should be kept afloat by thick armour, which can keep her afloat under any fire that the enemy can bring to bear upon her, and certainly should this be true, that the small armament of an enemy should never be able to destroy her. That has been the ground of the whole of my public agitation against such ships as you see here, to which more than a mere patch of armour in the centre has been denied, and of which ships it may be aptly said, and with the utmost truth, that the enemy needs no application of large guns for the destruction of such a body, but all he has to do is to open this up in part with his small armament, and there is the ever ready sea to enter in, to fill him, and to send him to the bottom; and if you can imagine such a thing brought about, just think of the feelings of the community, and of their indignation with the absurdity of people who allowed the enemy with their small guns to send these great ships to the bottom of the sea. I raise this point first, because it seems to me that this question of armament was given a first place in the deliberation of the Naval officers at the outport—and I do not know, for none of the papers tell me, why it was so; none of the papers show to me that Naval officers wished it to be so; all we know is that they were invited to decide on what the armament, and the disposition of the armament, should be, and that that was made (as I read the Parliamentary papers) the matter of primary consideration, whereas I think it ought to be a matter of secondary consideration. It seems to me a strange idea that a first-class British battle-ship should be so denied main armour as to be sent to the bottom readily, early in a battle, and that then the country should be told, "Yes, it is true she has gone to the bottom for want of armour, but she had a splendid minor armament, and no end of six-inch guns, and as to three-pounders, quick-firing guns, she had an enormous, an endless quantity. I do not understand the principle of proceeding with our first-class battle-ships in that way. I am afraid that my remarks may be rather disjointed because I propose to take the paper as it stands, but incidentally in the paper I notice in several places a good deal of stress is laid on the fact—the statement, rather—that the *Fury* was re-designed; that her design was cancelled, and that she was converted into the *Dreadnought;* and in the paper its able author refers us to a paper which Sir Nathaniel Barnaby read describing this recon-

struction; and when you are told that a design has been cancelled, and that it has been designed *de novo*, and that the *Dreadnought* has no relation to the *Fury*, I wonder what you will say when I tell you that Sir Nathaniel Barnaby in that paper states that the *Fury* was framed and nearly plated—plated up to the armour shelf—and that the changes made in her involved no undoing of the work which had already been done. So that, I submit, all the reconstruction that was undergone must have been reconstruction at or above the water-line.

Mr. W. H. White, F.R.S. (Vice-President): If Sir Edward Reed will pardon my interrupting him, perhaps he will allow me to state the facts. I am sure Sir Edward Reed would not wish to dwell at all on this. The facts are that at the central portion of the ship she was in frame up to the armour shelf, as Sir Nathaniel Barnaby has stated. Mr. Martin was the chief constructor at Pembroke at the time. I see him in the room, and he will tell you, if my words require confirmation, that a certain portion of the forward part of the ship had to be taken down. When I spoke of the ship as being re-designed, I meant that completely new drawings were sent out, and I have seen in the tabular statements that even the beam of the ship was altered.

Sir Edward Reed: I would like to read the language of Sir Nathaniel Barnaby in the paper which I refer to. I have not the paper, but I wrote it down just now. "She was in frame"—it does not say partly in frame or in the central part—"and partly plated up to the armour shelf for a considerable portion of her length." And in another place he says: "She underwent no change." It is, however, of no great importance.

Admiral R. Mayne, C.B., M.P.: May I ask you, Sir Edward, to continue Sir Nathaniel Barnaby's remark? You will find he says he does not compare the *Fury* and the *Dreadnought*, because she was entirely a re-designed ship. I would merely call attention to this.

Sir Edward Reed: My honourable and gallant friend has misunderstood my point altogether. I do not for a moment say that Sir Nathaniel Barnaby did not state that the ship was re-designed; it was stated in his paper, as the gallant Admiral says. But my point is, that whatever re-designing was done, was done in the main, at any rate, above water, and the main change was this. Mr. White will, perhaps, allow me to refer to his diagram. The principal change was this: that in the *Devastation* we were squeezed down in size by the First Lord, and we adopted, as will be seen here, the breastwork system. When the *Fury* came forward we were allowed a somewhat larger displacement—I think a good deal larger, if I remember rightly—and in reference to her we adopted the same arrangement. Now, I happened to make a visit to Russia just after I left the service, and I went over the *Peter the Great* with my friend Admiral Popoff. I noticed that this arrangement was adopted, and I suggested to him that it might be desirable, and would involve extremely little additional armour, to carry out the two sides, and to fill in space between them. When I came back I found that this was done in the case of the *Fury*, and that they had turned her into the *Dreadnought*, with possibly some other meritorious changes. I would like to say in passing, my Lord, that I am not so sure that it is a good thing in all respects to have the side going up to a great height continuously without any change of breadth, for the reason that it tends undoubtedly to set up heavy rolling. Heavy rolling is a thing for which little provision is made in Her Majesty's ships of the present day. However, I noticed a smile when I said it was of little importance. I meant from my point of view. It is a matter not only of little importance, my Lord, but it is a matter of no importance. I will allow my antagonists the full value of stating that they reconstructed her from keel to gunwale, or any other statement that they choose to take into their minds and believe. It is of no

consequence to me at all. Now, the next passage I have marked has reference to the principle of concentration. Mr. White says: "The principle of concentration pushed to an extreme has serious disadvantages and drawbacks, although it enables greater thicknesses of armour to be used within any fixed limit of weight, since it reduces the area to be protected." Now, my Lord, my objection to all these ships, and the reason that I denounce them as bases of naval construction, is this: that they carry such enormous quantities of weight, and that they cost such enormous sums of money for armour-plating, which does nothing whatever to save the ship when she is in danger of being injured by heavy fire. That is my objection. Now, let us look at the design which is before us. Here we have these two towers—redoubts, I think they are called. It is obvious that if you cut these redoubts here, and open the armour out along the side, and do the same with the other, you would have to do only what was done in the *Nile* and *Trafalgar*—to fill in a comparatively short space with thick armour. Put *there, i.e.*, put upon the side, the armour is of immeasurable value to you as regards the safety of the ship and your inability to capsize and sink her by injury done to her by gun fire; but put where it is, it gives you next to no advantage at all in these respects. I do not suppose Mr. White will claim much advantage from it as regards stability. Put as it is there, it gives next to no advantage as a contribution to the safety of the ship in battle; and, let others think as they may, I will do nothing that will either sanction the application of the public money of the country, or endanger the lives of our seamen and officers, in ships designed for line-of-battle ships which are not provided with the fundamental quality of being able to keep afloat. Now, Mr. White has taken advantage in the paper, most naturally, of a good many circumstances that are open to him to make available for this discussion; but, my Lord, I cannot allow Mr. White all the advantages which he assumes. Now, in the first place, let us consider what has happened in the case of the *Nile* and the *Trafalgar*. What has happened there is that Parliament, who votes the money for these ships, had put before it a design for a ship of 12,000 tons to conform to certain conditions and perform certain objects. Before we can get here to discuss this question the *Nile* and the *Trafalgar* have undergone a change, and that has happened which seems to have happened to every ship for years past—that we no longer know them. Mr. White coolly stands here as representing, mark you, the very office which has sunk her from 12,000 to 12,500 tons, and seeks to take advantage of his own default, and to put me out in my calculations and statements, because, when it suits him, he takes the *Trafalgar* as she was designed, and, when it suits him, he naturally takes her as she is going to be. I object to his taking her as he has made her. I base my comparisons of this new ship with the *Nile* as designed; and I object altogether, as I am of opinion I have a perfect right to do, to having her put before us in her altered condition. But, my Lord, this very consideration brings me to the condemnation which I make of the narrow belt. Allow me to put it to you in this way. There are the *Nile* and *Trafalgar*; they have been overburdened by 500 tons or thereabouts. Now, what has happened to them as fighting ships? No officer and no man need hesitate for one single moment more now than he would if the ships had been built as designed, to go with them into battle. On the contrary, the *Nile* and the *Trafalgar*, as they now are, have 500 tons additional immersion, and are better fighting ships than before—better as regards the particular point to which I always seek to fix the public mind and attention, namely, the ability of the ships to keep afloat, for the reason that by the over-immersion of one foot their armour has gone a foot below the water more than it was, and it was sufficiently low before. The *Nile* and the *Trafalgar* could afford, by virtue of their elevated sides, the extra immersion which has befallen them, and which befals every ship, apparently, that we hear of; but if we take this new ship, and put her down an extra foot, what would happen? The three-foot margin which has been allowed her, and which, to my mind, is little enough, would, of course, at once become

a two-foot margin, and then we should get into this absurd position—that if you breach the sides of the ship and let the sea in her, or breach her below the water or anyhow and get a little water in her, then the whole thick armour protection is gone from her, and the capsize has commenced, and you have sacrificed your ship precisely because you have adopted the narrow belt, instead of cleaving to the high side of the *Nile* and the *Trafalgar*, or some approach thereto. That illustrates one of the points which I attach great importance to. I hope it will be understood that I know, and I agree with, all the difficulties there are, if you accept all the conditions which have been imposed, as Mr. White says, on himself. I do not for a single moment want to call into question, and never have called into question, either in his case or in the case of his predecessor, any of their calculations, or any of their views or principles. I have not the slightest doubt that he is obliged to stand idly by and take all the guns and other conditions which he says the Board of Admiralty impose upon him, because I notice he frequently in his paper retreats behind the instructions of the Board of Admiralty. Although he does that, I do not doubt that he could work out the given particulars of this or any other design very well; I am perfectly certain he is capable of doing it. But, my Lord, why I am rather disposed to visit those designs upon the constructor, possibly a little unfairly, is this—that whenever I see a new ship laid down, or a notice of it in *The Times*, I always find it says, designed by Mr. W. H. White; and that being so, as Mr. White stands before the world as the responsible designer, and we have no means—unless he is good enough to tell us—of knowing what amount of pressure is put upon him, we are obliged to hold him responsible for that to which his name appears.

Mr. W. H. White: Hear, hear.

Sir Edward Reed: Then I will take the principle of this auxiliary armament. Does Mr. White himself put the possession of a large auxiliary armament before the provision of abundant armour defence for the flotation and stability of the ship? If he does, then I disagree with him absolutely. I shall oppose and obstruct him to the best of my ability, because I think it is of the first importance that we should make the ship keep afloat, and then, secondly, give her what armament you like her to have. Now, Mr. White has complained very naturally of my stating that these ships were of the *Admiral* type, and he has given a number of reasons—three reasons—why they are not of the *Admiral* type, and he made a point, and a very fair and legitimate point, which excited a natural laugh, in which I joined, when he intimated that the able and gallant officers who composed the Board of Admiralty did not know what they were about. Well, but how did the question arise? The question arose from the fact that the First Lord of the Admiralty, in his written paper, if I remember rightly—certainly in his speech—stated to Parliament that these ships, as regards the armour defence, were ships much more of the *Nile* and *Trafalgar* type than of the *Admiral* class. I admit that in this matter Mr. White gets an advantage from his five-inch armour, but, to tell the honest truth, my Lord, I attach no importance to it for my purpose, for the reason that I do not suppose there is a man in the room who can doubt that the armament of an enemy would breach and knock to pieces the five inches of armour with his larger guns. When that is done, and as soon as that is done, the ship actually becomes of the *Admiral* type rather than of the *Nile* and *Trafalgar* type. The fundamental distinction between the two types is that in the *Nile* type the armour goes up to another deck above the water, and in this type it does not—the thick armour I mean—and therefore I find the First Lord of the Admiralty is under a total misapprehension as to the nature of the armour of the ships. When he was making his statement, I forget whether it was in print, but when he was making his speech to Parliament he certainly put that doctrine forward, and made the House of Commons understand—if I had not been there to stop it and correct him—that the armour of these ships was

disposed after the fashion of the *Nile* and *Trafalgar*. Well, I think it most important, if the Admiralty ships are going to be as they are desired, if they are going to be a departure from an approved type, that the House of Commons should know the truth. My inference was this: I wondered then, and I wonder now—I may get the information from persons who can speak with authority—whether at the time the Naval Lords of the Admiralty gave their approval to this design, they were aware that they were producing a vessel such as is represented on Plate VIII. Now, my Lord, allow me to refer to that diagram. I have shown this diagram, comparing the new ship with the *Bellerophon*, not from any desire to refer to the intrinsic merits of my first ironclad; but I take it as a case of what was thought desirable twenty or twenty-five years ago with regard to the raising of the armour above the water, and the descent of the armour below water. The inner figure there is the *Bellerophon*. The inclination given is the inclination which lifts the lower edge of the *Bellerophon's* armour out of the water; and outside of her I have put the new design to the same scale. That is where the new first-class British line-of-battle ship would be when she was put to the same inclination as the *Bellerophon* could have gone to without exposing her bottom at all. You see her armour is lifted about four or five feet out of the water on one side, and is plunged as much under

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Mr. W. H. White: May I explain, my Lord, that when I spoke with reference to this diagram I pointed out that the five-inch steel armour of the new ships was, no doubt, accidentally omitted, and I may now add that the armour shown on the *Bellerophon* is five inches thick of iron.

Sir Edward Reed: I should like to correct my friend by telling him it is six inches thick.

Mr. W. H. White: Not before and abaft the battery. I took the trouble to look the matter up.

Sir Edward Reed: Do not let us descend into an altercation. We are not now discussing thickness of armour, but height and depth. I would say one thing in fairness to Mr. White: I notice that he gives the depth of the armour below the water of the *Bellerophon* at six feet. I have given it differently. I cannot remember at this moment what I have taken, but I know it is more than six feet, the reason being that I took it from the legend of the ship, which was the only document I had in the office giving me the information. Perhaps it is a little exaggerated, but it was not so intentionally. Now, let me refer to the other diagram, Plate IX. In the upper figure I have shown the condition of the thick armour of the new line-of-battle ships when the ship is inclined to such an extent as just lifts the lower edge of the armour to the surface on one side. You will see where the armour of this ship is on the other side. When you put the *Nile* to the same angle you will see her armour is not entirely out of the water on this side, and is very far from being all in the water on the other side. Now, my lord, that diagram illustrates the whole ground of my accusations and attacks upon this ship. What happened? Mr. White makes merry, very naturally, and in a very good-tempered spirit, over the accusations which I have directed against these vessels, and those responsible for them, and he says in one place, "I would like to know at what period the Admiralty Office decadence began."

Mr. W. H. White: Hear, hear.

Sir Edward Reed: I will tell him, sir; it began when the Admiralty Office turned out that ship (pointing to a diagram of the *Inflexible*). It did not begin in connection with the design of any of the ships that followed my retirement from the Admiralty until that ship was begun, and then the decadence commenced.

The President: Will you name the ship?

Sir Edward Reed: The *Inflexible*. Then the system of the *Inflexible* was exaggerated and made worse by having the armour cut down as well as cut short in the ships of the *Admiral* class, and the decadence was going on; and then the Admiralty changed, and now, without fear of being challenged in my statement, I say this, that when the present Government—no, not the present Government, because there was an interregnum during which we were in office six months from the other side of the House—but when the Conservative Government entered office in 1885, I went down to the Admiralty to see a distinguished naval officer in a high position of authority, and I asked him what was going to be the policy of the new Board, and he told me that the policy of the new Board was going to be this: That they would have no more ships of the *Admiral* class nor anything like it, but they would have the *Dreadnought* brought up to date. I will not be tempted into repeating what was said about the *Admiral* class, and I will tell you why I will not say it, because when we get before Parliamentary Committees we do not get the same answers to questions as we do when we are speaking in a less formal manner, and we have not yet got publicly the mind of the Naval Lords of the Admiralty touching the *Admiral* class. We have not got it, and it is a very important matter to me to know whether they realised that when they gave their provisional acceptance to this new type of ship now proposed, they were reverting to the practice of taking so much of the armour away from the side, and putting so much of it into a form in which it cannot be useful.

The President: But we are not a committee of scrutiny.

Sir Edward Reed: Now, my Lord, there is a point in this argument of Mr. White's to which I attach some importance, and which I see the value of. Mr. White points out that when you have your armament in redoubts, as in this ship, you cannot get the projectile from the outside into it, unless you either pierce the redoubt or wound a very small area of deck. I admit that that is a matter of great value, and I suppose that that is what was intended—although I did not understand it at the time—by a noble and gallant officer, whom I see present, who was present in the House of Commons the other night, when he spoke of the target being so small. I suppose it was that unless you penetrate the actual redoubt, you cannot injure the machinery of the guns; whereas, in the other case, if they were in the larger redoubt, a shell entering there might injure them more readily. I did not understand at the time what was intended, and I am not going to accept the argument now I see the point. But, my Lord, am I to be told—are we to be told—that for the sake of that advantage, for the sake of obtaining that reduced area of deck there, you would take away this wall of armour from the *Nile* and *Trafalgar*? that you will take away 16 in. of armour and put 5 in., and let all the enemy's large shells into your interior to work any mischief they can, rather than that you would screen the base of the turret from shells exploding anywhere in the citadel. In taking it away you, in my judgment, abandon the ability of the ship to keep afloat in action. Now, with regard to these vessels, I should like to be very fair about them. Mr. White pointed out, and with truth pointed out, as essential differences—and I was rather struck with the words, "essential differences"—between this type and the *Admiral* type, that the

armour is a certain extra percentage in length—the belt is. I admit that I have stated on every convenient occasion that I did not say these ships were so deficient of armour as the *Admirals* are. I have acknowledged that the belt is longer: I have acknowledged that it is about 1 in. higher vertically; that is to say, if you take into account the difference in breadth of the other vessels and this vessel, put them to a given inclination, this vessel's belt is about 1 in. better than the other vessels. I gave them the credit of that. I admit this also: I am prepared to admit with as much of the length of the vessel protected as is protected here, I do not think these vessels are so liable—nearly so liable—as most of the vessels of the *Admiral* class to this disastrous result: that when in this case you let water in her (these diagrams do not show the thing as it is, and you will kindly leave those redoubts out of your eye, because they are in the middle of the ship; they are not at the side), if you take this [*indicating*] as the shallow belt, if the water is admitted here, the end of this belt comes under the water, and then she goes on, going down by the head, and the belt is no earthly use to her, except in making the sinking a little slower, which is an advantage, no doubt, but not sufficient to justify the arrangement, in my opinion. Mr. White claims a great deal of value for this 5-in. armour, but nothing that he has said changes my opinion about it. I perfectly admit that with it you will keep out many small shells, and some serious explosive shells from the interior part. I admit more. I will admit that when the enemy's large guns attack your principal protected deck three feet above the water; when they do that there is some advantage—considerable advantage—in their having to go first through the 5-in. armour. But I deny that the 5-in. armour is of any great importance in the way of protecting the inside deck against the fire of the heavy guns, against which it ought to be proof. It is of some advantage. I do not know how far the deck has been thinned, or whether it has been thinned, but I notice in the table that there is a little extra weight allowed, 60 tons, and I suppose that the deck is as good as the deck of the *Admiral* class; but I cannot for a moment assent to Mr. White's view that it is better to bring your main armour nearer to the water's surface, and then put five inches above it, rather than to carry the solid heavy armour up to a much more reasonable height. My Lord, Mr. White made a very singular point, and the meeting laughed and seemed to enjoy it. They seemed to think that he had made a point against me when he took the pains to show, as he did two or three times over, that these ships are ridiculous in their absence of protection when you come to consider them inclined to one side, and consider the side on which the armour leaves the water. But that is one of the complaints I make, and if there is any doubt about it, perhaps I may be allowed to read from a letter which appeared in *The Times* of to-day, written several days ago, in which I pointed out, in pursuance of an idea which is fixed with me, that it was just as bad to have too little armour under the water as too little above it. I put it in this form: "No respect for the Board of Admiralty and its officers (many of whom I appreciate and admire), shall induce me to sanction for a moment, or fail to denounce with warmth and indignation, the spectacle now presented to the eyes of the Navy, the country, and the world, when the Admiralty propose to deny to our first-class battle-ships, of 75 ft. breadth and 14,000 tons, a belt of armour sufficiently broad to allow the ship some reasonable movement at sea without plunging all the armour on the depressed side much below the sea's surface, and at the same time raising the whole of it on the other side high above the water, thus exposing all her vitals to the shell-fire of the enemy." When I tell you that I only saw Mr. White's paper at half-past one this morning, and wrote this letter on April 4, you will see that the one has not been suggested by the other. Mr. White implies that by common consent my estimate of the serious risks inevitable with narrow belts is not endorsed. My Lord, I am sorry to say—I am grieved to have to say, that while I cannot admit that I know the contrary, I cannot publicly give my authority. I am sorry to say if Mr.

White supposes that foreign Governments are satisfied with ships circumstanced like ours in this respect, his information is marvellously different from my own. I have had information as to the deep anxieties which rest upon certain persons in certain navies for the very reason that they have brought about the state of things in their vessels which I am now condemning; and I believe myself that this country would be outraged beyond everything at the course which the naval construction of the last few years has pursued (excluding the *Nile* and *Trafalgar*) were it not for the fact that foreign Governments have to a very large extent made the same kind of error, although not the error of keeping their belts short as well as shallow, except in certain very few cases. Mr. White, following the footsteps of his distinguished chief, the First Lord of the Admiralty, makes a bit of a point about my wanting belts that must be comparatively shallow in cruisers, and objecting to them in battle-ships. Well, I should think that anyone who knows the difference between a battle-ship and a cruiser must be aware that a cruiser is a ship in which you can and must make sacrifices, because she is not under the obligation that the battle-ship is. The British line-of-battle ship is, and I hope always will be, whether you give them armour or whether you deny it, under the obligation of finding the enemy and closing with him, and fighting it out. The cruiser is under no such obligation, and the difference ought to be known to everyone engaged in these matters.

Captain C. Penrose FitzGerald, R.N.: Why is not the cruiser to close and fight?

Sir Edward Reed: Because she is not put forward for the primary defence of the country; she is put to perform such services as she is adapted for, in distant seas, considering her power and speed. I do not think you can expect to make the same demands for every cruiser as you would for a line-of-battle ship. The differences between the requirements of cruisers and line-of-battle ships are well known. Now Mr. White has spoken (and I must confess I am surprised in the presence of recent circumstances that he should have done so) about the "coal protection" of certain vessels. Well, if anyone who is a regular reader of *The Times* newspaper, happened to look at the naval intelligence a week or two ago, he would have seen a remarkable instance of the utility of coal protection as applied in Her Majesty's Navy. The case given was that of the *Orlando*, which had been unfortunate enough to have all her armour disappear under the water. Nobody seems to care about that—that seems to be quite satisfactory; but there it is. They gave her some coal armour, and they said in using this armour on the voyage to Australia, owing to the additional work imposed upon the men, and the circumstances of the stokeholds and the working of the ship, the stokers had to leave the holds, the seamen had to go down and work the fires, and certain great changes were being made in some of the other cruisers in the dockyard to bring about a remedy for this unfortunate state of things. I am rather surprised that any officer of the Admiralty should refer to that subject. My Lord, Mr. White reminds us that the under-water portions are unarmoured, while the sides and bottoms of war-ships are, moreover, exposed to serious damage in action by submarine torpedoes and by ramming. Yes, but surely that is not a consideration which makes in favour of a low armour belt. We are told that, by the ram and the torpedo you are liable to get a great deal of water let into the interior of the ship below the belt; to say that that is a good reason for having a shallow belt, appears to me an absurdity. I confess it seems to me to operate in the opposite direction, and to operate most powerfully in that direction, and I really do not understand an argument of that character. Now, Mr. White makes one very comprehensive statement of claim against me. He says it is apparent throughout my utterances on this question of armour protection that there is no general or comprehensive survey, and no apportioning of the many risks. That is quite true if you include keeping the ships afloat among the risks that you are going to apportion. I

want to know, my Lord, what has happened to this country to make it impossible for us to have an invulnerable platform on which to send our officers and men into the Channel. There is nothing but the substitution of the minor considerations for the major. Mr. White would do to-day what Sir Nathaniel Barnaby did last evening in another place—admit that there is no difficulty whatever in producing a ship which neither guns nor torpedoes can dispose of. Sir Nathaniel even went beyond that, and mentioned other matters which might be protected; but I say, and maintain, that the platform of a line-of-battle ship can be protected on something like the dimensions that you are dealing with in these new designs.

Mr. W. H. White: No, sir.

Sir Edward Reed: Then I should like to say this, and perhaps this will answer part of Mr. White's paper—I should like to say that I have made a study of what can be done in this matter, and I find that with less than the displacement of this ship, a ship can be produced with armour as thick as hers, and enough of it for any purpose. I am very sorry to be forced into this statement, because it seems an improper one almost; but I have, nevertheless, satisfied myself that it can be done, and that it can be done in association with a very much higher speed than that ship is to have. Now, on the question of the speed, Mr. White did not make himself, if he will excuse me for saying so, at all clear. He poked a little genial fun at my stating that a ship of 14,000 tons would not be driven faster with 13,000-horse power than a ship of 12,000 tons would be driven by 12,000-horse power; but I should like to ask Mr. White whether he intends to imply that this ship is not a more difficult ship to drive than the *Nile* and the *Trafalgar*? If you take the draught as being the same, and then take the length and breadth, and multiply them together, and make a Rule of Three sum, and apportion them to the displacement in each case, you will find that you have a much larger displacement to drive, per horse power, in this ship than in the *Nile* and *Trafalgar*.

Mr. W. H. White: The draught is one foot less.

Sir Edward Reed: I do not take Mr. White's spoilt *Nile* and *Trafalgar*, but the unspoilt *Nile* and *Trafalgar* as presented to Parliament. Mr. White's paper shows the draught is not less, but precisely the same.

Mr. W. H. White: Two inches less.

Sir Edward Reed: I have tried it in various ways this morning, and I would not speak with absolute confidence, but I should like, when Mr. White replies, that he should explain how it happens that with a ship 380 by 75 feet, and over 14,000 tons displacement, you get a better form for speed—according to him a great deal better—than you have in the other case.

Mr. W. H. White: For high speed.

Sir Edward Reed: I suppose if it is good for high speed, it would not be very bad for a somewhat lower speed.

Mr. W. H. White: That does not follow, and has not followed.

Sir Edward Reed: I quite admit it does not follow, but certainly I think Mr. White will not stand here and contend that, if you wanted him to design you a fast ship, the way to do so is to impose upon her a very much larger tonnage for a given horse power than you would otherwise be satisfied with. As I understand him, that really is the substance of his contention.

Mr. J. I. Thornycroft (Vice-President): I may say that I believe that is quite true.

Mr. W. H. White: You mean, what I say.

Mr. J. I. Thornycroft (Vice-President): Yes.

Sir Edward Reed: Then, if it is true, it can be explained, but it has not been explained here—only stated that it is true, but it seems to be rather the other way. Now, my Lord, I must say a word about the point of speed being cheaply obtained. Upon that point I wish to say that the form that Mr. White's criticism took was not at all consistent with the idea that I wished to express. What I wished to convey is this. Before he began, and when I began to deal with ironclads, this sort of figures would hold; that is, if you wanted an engine of 4,000 I.H.P. you would require to have about 750 tons of weight to get it. Now, with 750 tons of weight you can have an engine of more like 10,000 I.H.P., speaking roughly, and consequently I contend that where you are able with a given weight to get more than double the power you could when those ironclad designs began, you do, in that sense, get speed much more cheaply than you could possibly do in those days. That is all I meant, and I think that is perfectly just and right.

Mr. W. H. White: The remark made was that speed was cheaply obtained, and not power.

Sir Edward Reed: Can Mr. White get speed without power? To my mind they are synonymous for the purposes of my argument. I see no difference at all. Now, my Lord, let me say if power—because I really must claim to use them as synonymous for the purpose of my argument—is not cheaply attained, and speed with it, how does it happen that we have got in the *Blake* and *Blenheim*, I think, 22,000 I.H.P.?

Mr. W. H. White: 20,000.

Sir Edward Reed: I would like to ask the meeting whether I am not justified in saying that, if in a ship of 9,000 tons you can carry machinery of 20,000 I.H.P., there is or can be any great difficulty in getting engines much more powerful than those proposed (13,000 I.H.P.) in these 14,000 ton ships, with speed corresponding with it, because you would only have to apply these improvements which he has discovered, which no doubt he will some day lay before us, and which Mr. Thornycroft is so thoroughly a master of, apparently, in order to enable him to pass up to the highest speed which I should care to see. Now about the coal supply; and here, my Lord, I come to a point which is one of very considerable importance. Mr. White said something in favour of 900 tons of coal being a suitable coal supply for this ship. Well, if he is content to stand upon that, and let this meeting and the world suppose that that is his idea of the coal supply of a first-class line-of-battle ship, which is going to keep us great and strong in the Mediterranean, and perform varied services, then I have not the slightest desire to say anything more about it. If other people agree with him, I can only express my astonishment, and maintain in silence my complete dissent. Now Mr. White has made free use in his paper, most free and repeated use of the "Board margin." I want to know what is his Board margin? What has happened is this. This Board of Admiralty, except in so far as it had undergone some changes since 1885—it was in the main reconstituted in 1886, as it had been in 1885—being alarmed and horrified, I suppose, with the over-draught of so many ships, laid down this rule: that in all future ships there should be reserved for such contingencies a margin of displacement of 4 per cent. The First Lord of the Admiralty made that statement deliberately, and in print, to the House of Commons. He has given it to us, and we have accepted it. We try and

believe all we can that comes from the Government as a promise and an engagement. The First Lord of the Admiralty promised that we should have in every ship a margin of 4 per cent. displacement, for the purpose of meeting these unforeseen contingencies—unforeseen, but apparently as certain as the day; and now Mr. White comes down and tells us he is going to appropriate the Board margin, which is wanted for all these other things, and turn it into additional coal supply!

Mr. W. H. White: No.

Sir Edward Reed: He does in the paper repeatedly: he gives a table in one place.

Mr. W. H. White: What page is it?

Sir Edward Reed: The Board margin, says Mr. White, is equivalent to an enlarged coal supply. How can it be equivalent to an enlarged coal supply when it belongs to the House of Commons for other purposes? It is a pledge and a promise to us, and I must say, that unless I greatly misconceive this design, that when these ships are finished, with all the skill and care that Mr. White and others may bring to bear upon their construction, they will not have all the Board margin available; because the contingencies and exigencies of the future years will tend to use it up; at any rate, the experience of the future will be different from the experience of the past if that is not the case. My Lord, I feel that I have spoken at great length, but I do not feel that I have exceeded my duty in the matter, because the questions involved are questions of immense public importance. I need not tell you, my Lord—I need not tell this meeting—that the late Director of Naval Construction being an immediate and close relative of my own, and, like Mr. White, a personal friend, I should never have gone into this public action, except on the basis of a profound conviction that it is unwise to spare the armour, and cut it down to narrow, very, very narrow belts in these first-class ships. It is a conviction that I cannot get out of my mind. Mr. White says it is only an opinion; yes, my Lord, but if there is nothing in the opinion, how does it happen that in 1885 the *Nile* and *Trafalgar* were laid down, based avowedly upon the views that I had been advocating. When the *Nile* and *Trafalgar* were laid down I immediately became, not an antagonist of the Admiralty Office, but an apologist and friend. I repeatedly opposed in Parliament the attacks of men on my own side of the House, with regard to the *Nile* and *Trafalgar*, for the simple reason that from them was removed what I regarded as this damning feature, so disastrous to the life and security of our Navy. Now that I find that security again taken away, I attack this Admiralty, and this ship, and this Constructor, and the Controller, and everybody else who supports it; and I should not care if it were my father or my brother, or anybody else who designed her, I would attack the design, because I foresee that in the hour of battle we may see these great ships going to the bottom in a manner too horrible to contemplate, because of this sparing of the armour in favour of minor considerations. I am sorry, my Lord, I cannot say how sorry I am, to have to assume this attitude with regard to Mr. White. I hope everybody in the room knows that I have no question whatever in my mind as to the perfect competence of Mr. White to work out a design, and have it carried through. That is not the sort of thing I meant when I complained of incompetence. The incompetence of which I complain is that by reason of which, my Lord, we do not get—owing to the force of circumstances, owing to the divided responsibility, owing to the indefiniteness of the action there—the best out of any particular individual man, be he Naval Officer or Naval Architect; and I must say that denouncing the Admiralty Office for incompetence seems to have had one very good result—although no result would justify it if it were not a conviction of mine—that we know more about these ships now than we should have known for the next three years if I had not denounced them. I can

only conclude by saying that in this, and in every debate in which I am concerned, I shall not introduce any other feeling whatever than a strong and irrepressible desire to keep the Navy of this country, and every ship belonging to it, as strong and safe as it possibly can be made.

Lord Armstrong, C.B., D.C.L., F.R.S. (Vice-President): My Lord and gentlemen, the interest of this discussion obviously turns altogether upon the debate between the two principal champions who appear on this occasion, and I cannot help thinking that you will regard with very little interest the observations of one who has merely listened to the paper, and has had no opportunity of digesting its contents and framing proper comments upon it. I should much prefer to defer anything that I might have to say, or anything that I might have to write, until I have had that opportunity of considering the subject. With regard to the question of armour, it certainly appears to me, from all that we have heard both from Mr. White and from Sir Edward Reed, and from all that we can gather from these numerous diagrams, that we may come to this conclusion, that if we render a ship absolutely safe from being sunk by modern artillery we shall simply eliminate its power of sinking anything else. It is clear to me we must have a compromise between defensive power and offensive power, and as far as I can judge from a hasty inspection of these diagrams, and from listening to all that has been said upon the subject, it does appear to me that the compromise which is presented by these latest designs, especially by the battle-ship of the barbette stamp, that we have in that ship the best compromise between defensive power and offensive power that has yet been submitted to the public. However secure a so-called battle-ship may be made against the attacks of artillery, there still remain other modes of attack against which she is no more secure than an absolutely unarmed ship. She is liable to be attacked by torpedoes or by rams exactly the same as any unarmoured ship. If it be possible, as Sir Edward Reed said, to devise a ship that shall be secure not only against artillery fire, but against the attack of torpedoes or rams, and which shall at the same time not exceed in weight or dimensions the vessels which are exhibited here, then I can only say it would be a matter of extreme interest if we had before us the particulars of the designs by which such results can be attained. Upon the whole, what I have heard and what I have learned upon this occasion only tends to increase the disfavour with which I look upon the armoured class of battle-ships as a whole. I cannot lose sight of the fact that, do what we will, we cannot make battle-ships absolutely invulnerable nor absolutely secure against sinkage, and that we incur so enormous a cost in their construction that we cannot have a numerous Navy if we devote our resources chiefly to the production of such ships. We require for the protection of our commerce and for general services that our Navy should be extremely numerous, and the only possible means of obtaining a Navy of sufficient number for that purpose is to restrict our expenditure upon ships of this class, and increase our expenditure upon ships of the cruiser class. The question of policy is hardly involved in the present paper, which is confined to questions of construction. If it had been a question of policy between cruisers and battle-ships, I might have had more to say upon the subject, but observations upon that point lie outside the sphere of the present paper. I should rather, therefore, for the present abstain from troubling you with any further observations.

Captain Lord Charles Beresford, R.N., C.B., M.P. (Visitor): My Lord and gentlemen, in obedience to the Chairman's command, I will say a few words, although I must confess I did not expect to have to speak to-day. I think that Lord Armstrong hit the right nail on the head in this great controversy, as to what is the best platform that you can build to send your men and guns to sea to fight an action with. The controversy is between the armament and the armour; and Lord Armstrong, in my humble opinion, hit the right nail on the head when he said, if

you build a ship with the capabilities which Sir Edward Reed demands, and justly demands, from his point of view, you would have nothing offensive to hit your enemy with. That is the real point, as I look at it. A ship is always a compromise. In the very few words which I shall have the honour to say to the meeting, I should like to take the question out of the constructors' argument, where it has been up to the present, and give my view as a seaman, one of the men who have to fight the ships; and if I did not really think that my views were those of my brother officers, I would not stand at this table and speak them. May I say, in the first place, that I think Mr. White had done us very great service—whether Sir Edward Reed quite agrees with him, or whether other people agree—in having this question fought out publicly, in the light of day, so as to let people see which argument is sound and which is unsound. That is what we want, because the first question on which our existence depends is the strength of our battle fleet. I may, perhaps, touch first the question of armour. I think myself Sir Edward Reed's contention is wrong in regard to the new battle-ships. If Sir Edward Reed had stuck to that class of ship (the *Admirals*), or that class of ship (indicating diagrams), and they were going to be built, I for one would heartily agree with him, because I believe *that* to be a bad class of ship. We can never get anybody to say that they are responsible for that class of ship.

Captain C. Penrose FitzGerald: Which class do you mean?

Lord Charles Beresford: The *Admiral* class. My opinion is this: they are not armoured ships at all, because your first contention should be, with an armoured ship, that that ship cannot be put out of action unless the armour is pierced. With the *Admiral* class of ship, I believe the armour need not be pierced at all to put her out of action, but with a large auxiliary armament brought to bear upon her she may be put into a position to be capsized. Constructors will probably argue against me there, but they cannot argue against me from a seaman's point of view, which is, that when her fore and after compartments are filled her trim is altered, and, therefore, she becomes a totally different ship to fight. When the trim of the ship is altered, you alter both her speed and her helm, and if another vessel comes against a vessel of that class which has not arrived at that condition, I say that the other vessel should win the action. I throw this out because I object to that class of ship, and I have asked the Admiralty to try her. Why should not they put her in a dock and fill her fore and after compartments, and see what she will do? But they will not do it. I say it is altogether wrong that we should have that sort of ship without knowing what she will do when she comes into action. Where I do not agree with Sir Edward Reed in the argument is this: I say we ought to know what they are worth, but let us remember that we have got them, and we cannot build a lot more at the moment, and that having got them we ought, in my humble opinion, to get their exact value as fighting ships under the conditions in which they are. Having got them, we must do what Englishmen have always done, and that is, do the best we can with them. On the question of the armour of the new ships, Sir Edward Reed's contention is, I take it, that in the midship part of the ship, which is only protected by five inches of armour, if that is pierced, and undoubtedly it can be pierced by a heavy gun, that ship will be in the same condition that the *Admiral* class is in when her light ends are perforated. I do not agree with him at all, and I will try and give my reasons. The only thing you have to fear in the unarmoured part of the ship is shell fire. You need not fear the shot which will make a hole and go through it, and you will probably be able to plug it. The origin of armour was the damage done by shell fire. It was in the Black Sea war, when the Russians destroyed forts and Turkish ships because they had shell guns, and the Turks had no shell guns. Therefore the French began *La Gloire*, which was a ship designed to keep out shell fire. In all these engagements of battle ships, what you have to be afraid of is the shell fire, and not the heavy

shot. First of all, having adopted the Germans' idea, the constructors have put up that 5-in. steel. Now, what is the result of that? As far as we know at present—we want to get these things done at once, and therefore we must take things as they are, and not consider what is going to be done five or ten years hence—I believe the 5-in. will explode any shell, or nearly any shell, but certainly will explode the high explosive shells which are the new great danger. Therefore you only get on your armoured deck, even if it gets through the 5-in. plating, the fragments of the shell, instead of having the shell exploding on your deck. I do not think Sir Edward Reed's contention, as far as that part of the vessel goes, is accurate from that point of view.

Sir Edward Reed: Would not 16-in. armour have done that?

Lord Charles Beresford: Yes, perfectly; if we could have the *Nile* and *Trafalgar* armour, then I would be the first to agree to it, but it is impossible, and there must be a compromise. If you have the armour there you must either sacrifice your coal, or have a bigger ship, or materially reduce what we, as seamen, hold to be the most important thing of all, the large auxiliary armament. With regard to the large auxiliary armament, Sir Edward Reed in his remarks just now took, as he had a right to take, the two balances, the offensive and the defensive. I say distinctly as a seaman, and I hope one of my brother officers will get up and contradict me if he does not agree with me, that what we want in a ship is the offensive part. We are very glad to have as much defensive as we can, but we do not want to sacrifice in any particular whatever the offensive power which we possess of knocking the enemy into a cocked hat. We do not want to say, "You cannot hurt us," but what we want to say is, "We can hurt you." That is the best way to win the action. I cannot well put it plainer than that. Then there is another point, again. Great exception has been taken to the unarmoured ends. There again is the compromise. If the seaman and Mr. White come to the conclusion that these ends ought to be armoured, there is a great deal in that argument, I admit, because it strengthens your ram, and strengthens the power of your ship.

Mr. W. H. White: That was considered, as is shown in the Parliamentary papers.

Lord Charles Beresford: I have no doubt that everything was thoroughly considered, and that is the reason why I agree with these ships. Here again comes in the compromise. If you armoured these ships right away up to the end, as the French have done, you must have reduced your auxiliary armaments or the armour on the turrets. Mr. White has put the guns in a position so that they are almost always able to be in action on account of the small target they present, and the enormous thickness of armour upon them. I therefore think, with regard to the light ends, although from some points of view the argument is sound, still, taking the compromise, I think the Board of Admiralty have taken the wisest part of the compromise as it exists. May I go once more to the question of the auxiliary armament, of which I, for one, hold such a high opinion. We do not know at all what is going to happen in action in these days, nobody knows; I have said so before, I say so again. The only thing you do know is that twelve line-of-battle ships ought to beat six. But there is that which might happen—that one shot may win an action. I will put into the question the Hodgkiss 1 lb. shell. We do not know that that 1 lb. shell, by some luck coming into a battery such as the *Inflexible's*, where it is armoured all round and of great strength, and that 1 lb. shell bursting, her powder charge might not communicate the gas into the magazine, and so you would lose your ship. That possibility exists. Therefore, I say one shot may win an action. We may evade the argument, but the argument exists. Therefore, to follow my argument through, what we want to take into

account is this idea, that one shot may win an action, which I believe; and, therefore, we as seamen do hold the auxiliary armament to be of an enormous importance, as it may enable the captain of a ship to win an action under the conditions which I have started with. Now on the question of coal supply, and the question of speed, there is a very great diversity of opinion. I think Mr. White has demonstrated most clearly that these vessels are as good as can be made with the knowledge we have at this moment, and with the motive power in use at the present. I do not believe they could have made a better ship than these new ones, although Sir Edward Reed does not agree with it. I hope he will produce his ship. I think he will be the first to agree with me that, in a fair argument, theory is of no use to any man, and theoretical argument should be practically demonstrated. Mr. White and the Board of Admiralty have produced their ships, and I daresay I could find fault with those ships, but taking the compromise I think they are the best class of battle-ship you can make for the present day, having regard to the new high explosives. I hope Sir Edward Reed will produce something to the House of Commons which we shall think is a better class of vessel than that. If he can produce a better class of vessel than that, with that buoyancy, with that draught, and with that power of armament, I, for one, would give a vote for his vessels to-morrow. Now on the question of coal supply again, that is a very important question; and I think the coal supply of these vessels is as good, taking the compromise, as could reasonably be expected. May I go into the other question which has been talked about as to these ships. The meeting will forgive me going on about these ships, but it is most important for the country to get all these views expressed. I want my views upset. I do not say I am right, I can only give my views as I am called upon by the meeting to do. Some people say that the ships are too long, because they say that the tactician would not have a chance. There goes the compromise again. If you make a number of shorter ships, as many people advocate, with less tonnage, they say that these would win the action against a few of the bigger ships. I think Lord Armstrong said that. I agree with that if we were starting level with other countries. If they build large ships we must build large ships, and if they build a lot of small ships we must also build a lot of small ships. On our Navy depends our existence, and we must not run the chance, with our want of knowledge of actual warfare, of foreign nations getting something other than we have got which might win them the action if we came to hostility. As long as other nations go building vessels of that character, although they may have their faults—and the argument as to the expense and utility from the tactician's point of view is very sound—yet I am not prepared, for one, to say, that theoretically a number of small ships—not a number but an equivalent in value and weight as compared with the big—would be better than the big ship. That is my argument, and my reason for saying that so long as other nations build these ships England must perforce do the same. Handiness comes into this question of a short ship or a long ship, but in my humble opinion the best thing that you can have to enable you to win an action is speed. I know Sir George Elliot, if he is in the room, does not agree with me in this. I saw that Sir Arthur Hood, in a memorandum, said that the notes made by the Committee of Admirals on speed, in his opinion, were incorrect; because, he said, these ships did not want speed for they were so well found in offensive and defensive power. In my opinion that is all wrong. What you want is speed. What is the use of a ship being in an excellent position as regards offensive and defensive power if she is fighting a faster ship? Speed is the weather gauge; that is to say, you can engage if you have the speed, when and where you like, and the enemy cannot. There is the point of those Italian ships—which have many weak points—the *Italia* and the *Lepanto*; because they have the coal and the speed, and they have four 100-ton guns, I should not mind taking one of those ships against the French ships, or any of those, as long as I had the coal and the speed, because I could

bring the action about when I liked, to the best advantage to myself. What won us our actions in old days was that we always kept to windward of the enemy. The French never knew when you were going into action. They said: "When is this fellow coming down upon us?" They never knew. You could go into action when you liked, with your men fresh and well fed, and they were always in doubt as to when you were coming. That is exactly the same case now with reference to speed. I am sure that my brother officers will agree in that, if you have speed and your enemy has not speed. Now I should like to make one or two remarks, if the meeting will kindly let me, in answer to those of Sir Edward Reed. He spoke about the *Nile* being over draught, and the *Orlando*. The *Nile* was a foot over over draught. Well, that, in my opinion, was very, very wrong. Nobody was responsible for that, but that was owing to a system, that was so ludicrous that it is almost impossible to explain it to this meeting, under which they built our men-of-war at the Admiralty. Those new ships now have, in my humble opinion, for the first time been proposed to be built in a business-like way, and in the way in which any mercantile firm would build their own ships, or a man-of-war if they had to build one. They have got the seamen together (by the seamen I mean the engineers and the artillerymen, and the men who have got to fight the ships), and they have stated what they wanted to have, both in regard to capability of offence and defence, draught and speed. They put down what they wanted, and then sent for a naval architect, and said: With that buoyancy, with that draught, to carry such and such a weight, which includes the whole armament and weighting, what will you design? We want the armour in certain designated places. And the result has been the vessel whose diagram is on the wall. Now, that is a business-like method, if, as I believe, and as I have been told, when I asked the question in the House of Commons, the seamen did sit as they do in Germany, and found out accurately first what it was that they wanted. If that has been done—and I am informed it has—and their names put to a paper, so that they are responsible, then, although I might not agree with the ship which was the result of that, I should not say another word about it, because you must have a ruling power; somebody has got to lay down your ships, and this somebody, whoever he has been, has been put to do it in a business-like way for the first time, and, therefore, I should take the opinion of my brother officers against my own, who have been asked first of all, What do you want to fight with? And then they have gone to the Naval Constructor, and told him to make the best design he could under certain circumstances. Now, as to the Board margin. The Board margin is a very wise thing. We had a great deal to do with that when I was at the Admiralty, so I know a good deal about it. The Board margin was a very wise margin to allow for what must occur in the future, owing to the march of mechanical skill. We do not know but what in ten years' time there may be something invented which it is necessary for a ship to carry. You have designed your ship to carry certain weight, and this extra addition will, of course, bring her down in draught; and the Board margin is one of the wisest things, I think, that has ever been done by the Admiralty, because it allows for the march of science. Sir Edward Reed rather chaffed my friend, Mr. White, about his taking refuge beneath the Board margin. Now, that is a point upon which I do not agree with Sir Edward Reed at all. What I have objected to for many years has been what are called naval constructors' ships. My opinion is this: I say that the way you have built your ships up to date has not been fair on the naval constructor, any more than it has been on the seaman. It has been a haphazard way of doing it, but this has been a business-like way of building. Many of these ships, which Sir Nathaniel Barnaby and other people have been abused for building, were not built with any definite idea of the weight which they were to carry. The constructor was told to build such and such a thing, and he built such and such a thing; but he never consulted the seamen; and

extra armament was put in ; and then, after that, additional armour was placed on the ship. The result was that she had to carry an extra weight above what she was intended to carry. I am not abusing the naval constructors at all. I think they have done well under difficult circumstances ; but I say this, that for a fighting ship, the man first to consult is the man who has to go to sea in her and to fight her, and then the man who is to build her should ascertain how far he can meet the requirements of the man who has to fight her.

Sir Nathaniel Barnaby, K.C.B. (Vice-President) : As Lord Charles Beresford has referred to me, I should like to interject one word, to say that I have been familiar with the Admiralty modes of designing for many years, and we never failed to have the opinions of all the ablest Naval officers who were on the Boards of Admiralty. We always submitted every single point to them and to the Directors of Naval Ordnance. Therefore, Lord Charles Beresford is seriously misinformed if he thinks there can be any difference between the present system and that which has been pursued for many years.

Admiral Sir Houston Stewart, G.C.B. (Visitor) : I was Comptroller of the Navy for ten years, and if Lord Charles Beresford could call and obtain from the Admiralty all the designs of ships that emanated from the Admiralty during those ten years, he would find that all those designs were approved and signed by all the responsible Naval officers of the day.

Lord Charles Beresford : This again shows the utility of these discussions. My old friend and Captain, Admiral Sir Houston Stewart, has made out that I have made an incorrect statement, and so has Sir Nathaniel Barnaby, and I shall now ask that the designs of the *Admiral* class, with the minutes and remarks, are placed before the House of Commons. It would be most useful ; but I must tell the meeting I am confident I shall not be proved wrong. I shall fight this, and I am sure Sir Edward Reed will support me in this in the House of Commons, that the designs of these ships, with the minutes of the seamen and the Board at the time, are placed before the House of Commons for the country to read. There is no seaman in the room who will get up and say, I am sure, that the *Admiral* class is a good sort of fighting ship, or that that ship, which is two feet now over her draught——

Mr. W. H. White : No !

Lord Charles Beresford : She is not ?

Mr. W. H. White : No, the Parliamentary papers show that, by reason of additions made during the construction, the *Admiral* class are from 12 to 15 inches deeper than they were designed.

Lord Charles Beresford : Well, there is not such a great difference between 15 inches and two feet, but I go so far as to say it ought not to be one inch, and I will guarantee that those ships are not one inch if the design is carried out in its entirety without adding to it, and you stick to the Board margin ; I will guarantee that nothing of the sort occurs with these ships. My contention remains the same, that these ships were never seamen's ships. If they were, let us find out who the seamen were who recommended them. Also, that there is no real argument or reasoning that can be adduced —I will take Mr. White's figures—why these ships should have been 15 inches over their draught. One word more, Sir Edward Reed rather chaffed me about the question of the target. On the same principle that I think that one shot might win an action, I say that your ship should be so constructed as to hit

the enemy as often as ever you can. The same principle applies as to letting the enemy have as little to hit as you can. The advantage of the new class, in my humble opinion, is that you have nearly always an opportunity there of keeping your guns hammering at the enemy, whereas in the other class of ships your gun might be put out of action by a shot. Here it is almost impossible. It was put very well the other day by Mr. White in his paper; we keep on arguing as to what damage the ship will receive, and we quite forget the offensive power that we possess, that we are going to give the enemy the benefit of. We should stop him going on hammering all this time. That is a point which Sir Edward Reed forgets in his argument.

Sir Edward Reed: While you are afloat.

Lord Charles Beresford: I approve of that small target entirely, because although my ship may be damaged to a great extent I am still in the position, owing to the great defence round my guns, of being able to keep hammering at my enemy all the time the ships are in action. Well, Sir Edward Reed said something about foreign Governments and the narrow belts. I could not quite follow his argument there. I understood him to say that the foreign Governments were in a state of great trepidation through these narrow belts. I have been abroad lately to these foreign Governments, and I cannot say that I noticed any of this trepidation; but if this trepidation exists, why in the name of heaven do they go on building with the narrow belts? If they were going to desert the narrow belt, and take to the *Nile* and *Trafalgar* class, I would at once say that there is some force in Sir Edward Reed's argument, but I defy him at this moment abroad to name a ship that is not built with the narrow belt, and I will do more—the narrow belt on foreign ships is something like six inches less than the narrow belt we have, and I defy Sir Edward Reed to answer that, and I think I am right in making that statement as to the narrow belt. Sir Edward Reed referred to the system. I never lose a chance of abusing the system. I think the system at the Admiralty and the same at the War Office is ludicrous. It is utterly and entirely rotten—that is my view of it, and I have endeavoured to prove it. How these officers have done so well as they have done under the system, I cannot for the life of me understand. The seamen who go there, go there like they go everywhere else in the world. They say somebody did this before me, I can do it if he did it, and they do their level best, and it is hard and almost impossible for a seaman, under ordinary conditions, to resign his post at the Admiralty. He is sure to find somebody else to take it, and the whole thing will go on in the same way. I am not finding fault—I am merely stating facts. Public opinion I know has a bearing on this. The Government have granted a Royal Commission to go into the matter. I believe that Royal Commission, if it finds according to the evidence given, will bring about a system by which we shall get direct responsibility, and have none of the dreadful things which occur and have occurred up to this date. I am extremely obliged to you, my Lord and gentlemen, for having listened to what I have to say.

Admiral Sir Geoffrey Hornby, G.C.B. (Visitor): Lord Ravensworth, my lords, and gentlemen, I have come here following an officer whom I am sorry to say I must call a younger officer. In almost everything that he has said with reference to the service at large I entirely agree, and I think that he expresses the feelings of the greater part of the naval profession. But there is one thing in which I am not going to follow him, and that is in his criticisms of the designs of the ships, and so far I am afraid I am not fulfilling what is the object of this meeting. But my reason is this: I feel myself no more competent to criticise the design of a ship on paper than most of us are to criticise advantageously the design of an architect who is going to build us a house. We all know what that

criticism, when it has been yielded to, has brought forth; you remember the old proverb, "Fools build houses for wise men to live in." All I wish to point out is this, that I feel with reference to these ships as a Naval officer, and as one who has served on board ironclads, that I should be glad indeed to serve in such ships as these which are now shown us, because they seem to me to embody the idea which Lord Charles Beresford has so strongly put forward, and what I believe is the idea of every Naval officer, that they are ships of very great offensive power. They have great speed, which I consider is the highest quality that any ship can have; and, mind you, I do not want to put my opinion forward, I go upon the opinion of our highest authority, that of Lord Nelson. When I was in Australia I had the satisfaction of seeing the letter that he wrote on receiving into his squadron a new and fast line-of-battle ship, and he wrote to the Secretary of the Admiralty to say just this, "I hope soon to have an opportunity of using her." Now, I want to know, how are we to use our ships if we have not got the speed to bring them into action? There is another reason why I attribute great importance to this matter of speed—that it will give us superiority, until new foreign ships are built, over the Navies of other Governments; and in doing this I would refer to what I wrote some time ago to Sir Nathaniel Barnaby upon the great importance a foreign Navy attached to having rather higher speed, half a knot more speed. I said it makes this difference. If we met hostilely to-morrow, the faster ships command the operation, and the other ships must follow the lead of the officer commanding the faster fleet. That is a very serious consideration for any admiral. Any admiral who is happy enough to command a fleet in which six or seven, or perhaps the whole of these eight, ships are present, will prescribe the manœuvre. He will have the initiative, which we all know in war is such an enormous advantage. That brings me to another point which has been mentioned here, and upon which I cordially agree with what Lord Charles Beresford has said. I hold that a large and powerful ship is far more serviceable than small ships of the same value—the same cost, or the same displacement, whichever way you may put it—for this simple reason: it is an axiom in war that the best strength you can use is the concentrated strength, and, of course, if you can concentrate your strength in one ship, it can be more easily disposed than if it is distributed between two. This is the way I put the thing to myself:—What quality can I give up in this ship to enable me to carry the increased armour for greater defensive purposes; and I was at a loss to find out. The architect tells me that if I have increased armour I must give up coal endurance, I must give up speed, or I must give up fighting power. None of these should I be inclined to do. Again, there is another alternative. They say you must have a bigger ship. Now, I, as an Admiral, do not mean to say I object to a bigger ship, but I see the disadvantage of it. In ships of 400 ft. in length we find that when we work them in squadron we require very large harbours to put them in. We know perfectly well that in the case of war-ships of that length, they will encumber our wharfs tremendously when they come in to be coaled in a hurry. That also tells very much against very large and very long ships, and for those reasons—though I would not for a moment contest the point, if any architect said it is better on the whole to build larger ships—I think it better that we should have ships of medium size. I think it is right that Naval officers should keep those points in remembrance. Why I approve particularly of these ships is that I think, as Lord Charles Beresford said, that hitherto our ships have never been built in the right way, that is to say, you have never asked the man who is going to inhabit the house what sort of house he would like to have, but have disregarded the opinion that those gentlemen have given, the requirements that those gentlemen have laid down. But now these requirements have been carried out, very much to the satisfaction of those who are particularly concerned, that is, the officers who have to command your fleets. The names of the officers to whom these plans have been referred, and who have approved of them, are those of officers who have just left active service. Only one name

has been omitted, viz., that of Admiral Tryon, and that is in consequence of his having been laid up by an accident; but otherwise you have the opinion of the officer commanding the Channel Fleet, the officer lately in command of the China Fleet, and the officer lately commanding the India Fleet. I say myself you have got every name barring one which could guarantee the propriety of these ships, and for my part I feel on their opinions much more strongly than I do upon my own, that those ships are good, and will be serviceable ships, and such as any admiral will be fortunate to command.

Sir Nathaniel Barnaby, K.C.B. (Vice-President): My Lord and gentlemen, I hope to have the opportunity to-morrow at twelve o'clock of stating, as clearly as I can, the principles which have always guided me in my work at the Admiralty, and I only ask permission from you now, for a very few minutes, to say a word or two. Lord Charles Beresford just now, in speaking to one of his brother officers, said: "You do not know anything more about it (the behaviour of armour in actual war) than I do." But he had said before that the question of the use of shot against armour was not at all important. Now, let me emphasise just this one thing that I want to say, which is, that during a great many years there never was a target——

Lord Charles Beresford: May I be allowed to interrupt for one moment? I beg Sir Nathaniel Barnaby's pardon for interrupting him. I never said that shot against armour was unimportant. What I said was that the reason we wanted armour was to keep out the shell—the shell with the high explosives. I never said the shot was unimportant, but I said the shell was far more important.

Sir Nathaniel Barnaby: Then I will put it in this way. I will take Lord Charles Beresford's words, that the shot is of less importance, and of so much less importance that it seems to me they are content to have very thin armour, as we see upon this design here, a thing which I hold to be utterly wrong. And now I will go on with what I was going to say. There never was a target fired at for many years at Shoebury that I had not to go behind to see what had happened. For a great many years I was more familiar with the war that was going on between armour and guns than any naval officer in any navy, and I say that my experience of what happened behind those targets has been to me sometimes only too dreadful. I was always responsible for the way in which the target was made. I was responsible for the thickness of the armour put against the gun belt, and when I saw these things flying to pieces, and huge masses driven far beyond the target, I used to be feeling always, there must be thicker and ever thicker armour. But now, my Lord, we come—and Lord Charles Beresford approves of it—to armour of five inches. He says that is proof to the high explosive projectile. But I should like to ask whether it is not true that within the last few days there has been a shell of steel, a Holtzer shell with a high explosive bursting charge in it, which has been burst on the other side of a 6-in. armour plate? I should like to ask that question because I believe that is true; but, whether it is true or not, it is perfectly obvious that you will be able to get these high explosives through armour which is a great deal thicker than you are placing here. And now, sir, a point about the *Admiral* class. We have been told by the naval officers that speed is of the utmost consequence, and the power of hitting your enemy is of the utmost consequence, and yet, sir, these very same men have no words too bad to apply to the *Admiral* class. But the offensive power in speed and in guns of the *Admiral* class is practically the same as the offensive power of these new ships of 14,000 tons, very nearly the same. I will give you something, but they are very nearly the same. Now, my Lord, following Sir Edward Reed, you want more defence for that particular ship by way of armour. How do you get it? You get it by adding to the cost of the *Admiral*

class the precise cost of the ship which has been taken down from the wall, now a 17-knot fighting ship, with 22-ton guns. You add the precise cost of that ship complete with her guns to the cost of the *Admiral* class, in order to produce that class with the same speed and the same armament. Now, where is your consistency? And you do this: you actually take one ship, with 500 or 600 men in, and you expend on armour-plating her, apart from anything else, the precise cost of the Natural History Museum at South Kensington. I mention that because when my friends come to London I tell them: "I am going to show you a beautiful thing, one of the best things we have done: the Natural History Museum at South Kensington." The cost of the armour alone on one of these ships would build that place again. Now, I am one of those who believe in the magnificence of individual ships if you can get it, but, my Lord, if it is to be put against numbers of ships then I do not believe in it. I should like to call attention to this remarkable thing: that in the French Navy, and in our own Navy, you have the greater proportion of the Navy practically unprotected, so far as buoyancy and stability are concerned, and we are told by no less an authority than Admiral Hornby himself, that we shall have associated with the heavy iron-clads lighter ships, working with them, acting with them, and exposed, I suppose, to shot like themselves. We shall have ships, some of which have no protection whatever. You can take the lightest projectile and send it into the magazine or into the boilers, and you are sending those ships without thought, as it seems to me. You are building these, and you must send them into action. Now, I say, that while it may be a very good thing indeed to put a very large quantity of armour on ship A, for you to leave the rest of the ships of the alphabet, some of them with no armour at all, and some with very thin armour indeed, is a policy I cannot for the life of me understand. If you could do both, by all means do it. And now I should like to say this: Sir Edward Reed has referred to the *Inflexible* as the point at which the decadence began. Now, my Lord, I should like your permission to read a short extract from a letter from one of the members of the *Inflexible* committee, written after that committee had sat and after Sir Edward Reed had made his public criticisms upon what they had said. Sir Edward Reed did not appear before that committee; he did not give evidence before that committee, which was appointed to consider that ship. I do not object to his criticisms. I have no right to object in the least. I only say there was a committee appointed, a very powerful committee, to examine the question of that design, and Sir Edward Reed did not appear before it. The extract I refer to is this: "The report of the committee when rightly interpreted embodies and expresses their belief that the *Inflexible's* eminent superiority in fighting power has been secured by discarding determinately that very condition which the objectors have blindly assumed to be the most essential to her safety. I believe I express the opinion of my colleagues, as truly as my own, when I assert that if, in opposition to that conclusion, the clamour which has been raised should lead the Admiralty to hesitate in following out the principle on which the *Inflexible's* design is based, the hesitation will be quickly fatal to the supremacy of British naval power, for it will block the only avenue which opens to a secure advance in the race of improvement in defensive as well as offensive organisation in war-ships." Now, my Lord, I do believe that we have reached the point which is indicated by the distinguished man who wrote that paper. I believe we have reached the point where, following Sir Edward Reed, the Admiralty are wasting the national resources by piling up armour in a few ships.

Captain C. Penrose FitzGerald, R.N. (Associate): My Lord, I feel a little bit shy, for two reasons. I might describe it as shy in the abstract, and shy in the concrete—shy in the abstract because I see so many of my seniors here more competent to speak than I am, and I feel naturally a

little bit shy also in the concrete, of criticising the work of any naval architect. I have got rather into hot water by doing so. There has been a good deal of hard hitting. I for one have no objection to hard hitting, I am rather fond of it, but I cannot say that I have any great respect for those who are fond of hard hitting themselves, and do not like being hit back again. We all remember the little boy at school, who did not mind pitching into the other boys, but as soon as they hit him said, "Oh, no, that ain't fair," and ran away and told the master. But to pass on now to criticism. I should like to know, before I commence to criticise Mr. White's designs, how far we are privileged here to say what we think. We have had the House of Commons chucked at our heads on two or three occasions. I have no idea of claiming the breadth of privilege which is allowed to the House of Commons to say what they do of one another. That is quite beyond the limits of my ambition, but I should like to know, if I speak somewhat plainly of Mr. White's designs, that he will not take the law of me, as they call it.

Mr. W. H. White: Captain FitzGerald is at liberty to say anything he likes about my designs, and about me.

Captain C. Penrose FitzGerald: Well, my Lord, to proceed, and I shall not be very long. I have a great deal to say, but I must confine myself to one or two points. The first thing which I recognise in these ships is the practical completeness of the belt; and I observe, and I am sure my brother officers will agree with me largely, that there is no suggestion that before we go into action we should let a lot of water in at both ends of the ship, and that she would be rather the better for it. We were told that with perfect gravity about the *Admirals*, I cannot help mentioning it, because we were told, as you will remember, that it had been demonstrated by models and so on, that ships with partial belts could have the water let in at both ends, and they would be fightable, workable, habitable, and lose only a quarter of a knot of speed, I think it was. I am glad to see, and I am sure all Naval officers will be glad to see, that there is no suggestion of that kind in the new ships, that we are not asked to let the water in. We are to leave that to the enemy, and I venture to think that that is their business, and they will no doubt make a good job of it when the time comes. Now, the question of size and cost has been touched on by Sir Nathaniel Barnaby, and many other critics of these ships. I do not propose to follow Sir Edward Reed through his diagrams here. I do not know that he is a better judge of the risks of battle than we are. He may be, perhaps; but if we are prepared to accept the risks he points out to us, and the fearful pictures of drowning men and bursting boilers, and so on, why not? He is not going to fight in the ships. If we like to risk drowning for the sake of being able to hit harder, as Lord Charles Beresford put it, Lord bless my soul, let us have the risk, and let us be the judges: do not say anybody is a better judge of what we have to risk than we are. There has been a very strong criticism as to the cost and the size. Both have been condemned by Sir Nathaniel Barnaby, and I feel I cannot touch on that adequately now unless I refer to his paper of last night (and your Lordship will call me to order if I am out of order in doing so), of which you have all no doubt heard. It is so cognate to this question that I can hardly touch on the subject without referring to it, because I am of opinion that the alternative to size and cost is smallness and cheapness—not putting your eggs in one basket, as it is called, but distributing them in a great many. I, for one, cannot conceive why we should be asked to allow the question of cost to influence us. Sir Nathaniel Barnaby complains that naval officers cannot be got to consider cost, and tries to frighten us, if I may say so. I wish that picture of his was still up, because it was a very pretty picture. The alternative to the big ships, as they were designed at the Admiralty, was this ship of Sir Nathaniel Barnaby's

with 17 knots speed, and I think he said he could build three or four of those for the cost of one of these of the new design.

Sir Nathaniel Barnaby: It is exactly five for one of the new ships.

Captain C. Penrose FitzGerald: Five of Sir Nathaniel Barnaby's ships for one of this class. It seems on the face of it an exceedingly plausible assumption that you should build these five ships instead. This one ship—but if I might so describe the design—it is very much like a bee-hive with two popguns and a red-hot poker shoved up through the middle of it. I hope that is not actionable. I do not know how they are going to fight in those turrets. There is another point that comes in which must not be ignored; it is the moral effect—you hear a good deal talked about moral effect—of a large ship, and I say it is a perfectly false policy to deliberately build ships inferior to those of any foreign nation, on the assumption that you *may* have a vastly larger number of them. You know very well that a British ironclad is considered as a British ironclad, whether she is this ship or that ship—six British ironclads, seven British ironclads, or eight British ironclads. I say that you do a very wrong thing if you ask us to go into action on the assumption that we can bring ten of those ships to fight against four of those, or two of those.

Sir Nathaniel Barnaby: Two of those.

Captain C. Penrose FitzGerald: I would rather be in one of those. Your ten would be in each other's way, for one thing. There are all sorts of tactical considerations in manœuvring. They would probably ram each other. The first principle of warfare is to concentrate your forces, and, as Napoleon put it, to have the largest possible force in a given place at a given time—concentrated force, not dispersed force. These ships would be all over the place, and in each other's way, and they would very likely foul each other in the heat of action. They are insignificant ships, and not ships fit to fight against those, under any circumstances. Then comes the question of cost. Sir Nathaniel Barnaby tried to frighten us, if I might so say; he tried to make us remember that we had got such a tremendous value under our command. You will excuse me reading this, but it is quite relevant to the subject under discussion; it is out of the paper which he read last night, and suggests the alternative to these large ships of Mr. White's:—"It is difficult to get the sailor to appreciate a money basis. He has to fight in the ships. He sees that his personal chances of life in the smaller ship are less than they would be in the ship costing four times the money, and he naturally values his life and chances of personal victory more than he does gold. He cannot be expected to see that if four British ships, costing for the four a million of money, destroy or capture one ship of the enemy, costing the same amount, at the sacrifice by foundering of the ship which he might command, that that would be an altogether good result. It is necessary to bring well to the front the enormous increase in the value of the material of war which is entrusted to each captain and to each man in a modern ship." He then goes on to state it in figures. I say that we shall have difficulties enough in fighting, when the time comes, without introducing another element of caution, which is calculated to frighten us, about cost. What do we care about the cost? (Laughter.) It is no laughing matter. We go into action, and what do we stake? Our lives, our honour, the honour of our country, the honour of our profession and our flag. Do you want to put anything else on our backs? Why should you try to caution us about the cost o the ship, and make old women of your Naval officers? It amounts to saying, do not go near the shore, because you have a million of money under your charge, and do not go near the enemy,

whatever you do; your ship costs so much money. Does it not amount to that? We do not care two straws about the money. It is for you to settle that in the House of Commons. You go on trying to embarrass us. What I say is that you have something to defend which you call the British Empire, which is about the biggest value out, and you must have the best ships to defend it. I say the cost has nothing whatever to do with it. If you think it is worth defending, you must pay the money for the best ships that can be built, and the most expensive ships, if necessary; the proper number of them Sir Geoffrey Hornby has told you, which will give you a reasonable prospect of defending that property, not only in your own time, but of handing it down to your successors, undiminished in its extent, and with its honour unclouded.

Rear-Admiral P. H. Colomb, R.N. (Associate): My Lord and gentlemen, I think two distinct points must be apparent to the meeting from the discussions which have gone on. First of all, that you have got a number of naval officers in perfect agreement, which is not common; and, secondly, that the difficulties which the naval architect has to deal with in building battle-ships are the difficulties of opinion, that is to say, the naval architect has to go by the opinion of the day when he builds; and sometimes after he has built opinion turns somewhat against him. But what you will also observe is that very often naval opinion is not thoroughly gauged before the ships are built. Naval officers' opinions are quoted on certain propositions that have been put before them when they have not been shown what the alternatives were, but very often their opinions would have entirely altered had those alternatives been put before them. But there is one opinion which has been put forward from this platform, on which I take it there never has been or never could be any divergence whatever amongst naval officers; that is to say, you cannot begin to design a battle-ship until you have settled her armament, that her gun power is the first thing you have to settle, and everything else gives way to that. You go on afterwards to those other elements which the naval officer asks for, but you do not start with any other element but her gun power. Passing at once to the new designs, and the gravamen of the accusations against them, I think we must all be agreed that it comes to this, that the belt is not high enough above the water for its length. I have been myself for a great many years past the advocate of a belt which would be still less above the water than the belts of these ships, and from my point of view I think there is good reason why the belt should not be so high as it has been in some other ships. Lord Charles Beresford mentioned in another case, the question of smallness of target; that you must take advantage, not only of your power of resistance, but your power of avoiding the shot of the enemy. Now, I presume certain things about these ships. I do not know; perhaps Mr. White in his reply will state whether it is the fact or not. I assume that it is intended that these new designs shall roll less than ships of the *Admiral* class.

Mr. W. H. White: Yes.

Rear-Admiral P. H. Colomb: Mr. White says, yes, I am right. I take it that must be at the bottom of the design. If you have a ship like one of the *Admiral* class, with a belt extending only over a very small part of her length—from 40 to 45 per cent., I think Mr. White states—you would not only have it extended over a small part of her length, but over a very small part of her cubical capacity; that is to say, the amount of armoured buoyancy, calling it by the usual name, is exceedingly small. But now, when you extend your belt, as you do in these ships, fore and aft, not only have you extended the belt from 40 or 45 per cent. to 66 per cent. of the length, but if you take out the cubical capacity of these ships which is unprotected by the vertical armour, you would find that the proportion of unprotected part was still smaller than the proportion as given in lengths. I fancy that must be so,

because I take it that the ends of these ships are much finer ends than the others.' Now look how you stand with regard to this armoured belt. You have increased the length very considerably in proportion. You have increased the protected cubical capacity very greatly in proportion; you have got a ship which is going to roll less than former designs, and you have been able to make a ship which will roll less because of the very fact that you have armoured such a length of the water line. You are enabled to do that because you are not afraid of your stability being compromised by anything but heavy shot. Now, if you have a ship that does not roll, and you have a low armour-belt, you are in this condition, that a heavy shot passing through the 5-in. armour just here, above the thick belt, does not let the water into the body of the ship. Any shot going through that part passes above the armoured deck, and if it strikes the armoured deck and makes a hole in it, your men on board the ship are able with simple canvas, or arrangements of that sort, to instantly cover that hole so that the water does not penetrate below. The shot itself strikes the armoured deck, makes its hole before striking, and passes out through the other side, but the water that is let in through that hole does not pass below into the ship. It is on this upper deck, and I presume—I hope, that is to say—that means have been most carefully thought out for getting such water off as goes on to the deck in that way: I presume that must be so. Well, you see, the condition is this: that if that were an armoured belt raised in that way, with the armoured deck itself raised, you would have a very, very much larger target capable of being hit by the heavier shot—a much larger target, that is, which, if struck, would let the water directly into the ship, and you would have no means whatever of stopping that inflow; whereas, when the shot-hole is above the armoured deck in that way you have the means, because the hole into the actual ship is on the surface of the armoured deck, and you are outside it, and can cover it up outside. That is my argument, and I cannot help thinking it is a good one, for the low belt. I am sorry to say I hopelessly differ from Sir Edward Reed upon that point, for I do believe that the low belt, with the armoured deck kept low, as in these designs, is the safest way in which you can apply armour. I think we must all recollect that, notwithstanding all that has been said in this room to-day, it is perfectly hopeless to think of getting what Sir Edward Reed has called "an invulnerable platform." As has been said once or twice already, when we see the invulnerable platform we will believe in it, but not before. Now, I do not think it is at all necessary to go into the general questions which have been discussed. I should like to say, speaking as a Naval officer, about these designs, that this thing has not been done in a corner. That is to say, the Navy has been taken into the confidence of the constructors, and the Board of Admiralty, in a way that it never was before, and I think the result must be this, that never in this theatre will Naval officers be able to get up and denounce those ships if they turn out differently from what they expect, but that the constructors will be able to turn round upon us, and say, They are your ships; they are not ours. I think the Navy is quite prepared to accept the responsibility for these ships, for, taking them all in all, we are agreed generally they are as good as the opinion of the day will allow us to have them. But there is a point with reference to armour generally which I must put before the meeting, because it is so seldom touched upon. You have to recollect that what we build these ships for is to gain the victory. That is what they are built for; they are not built to protect the men; they are not built for any other purpose than to gain the victory when the time comes. How is the victory to be gained? In this room we have never discussed that question, so far as I know, at all. It is always assumed that the victory is to be gained by destroying the structure of the ship, by injuring her steering power, by stopping her locomotive power, by altering her trim, or by destroying her stability, and sinking her in that way. But all history tells us that hitherto victories have seldom been gained in that way. They are generally gained by the destruction of the men, by the men being maimed,

and put *hors de combat*. It is a very curious, but quite a certain fact, that in the case of all nations that have been engaged in naval war, the ships have always hauled down their colours when a certain number of men have been rendered *hors de combat*, and a victory has been gained by the ship which has placed most men *hors de combat* in a given time. What reason have we to suppose in the present day that the victory will not be gained just in the same way that it used to be? To my mind, in the *Admiral* class one of the most serious difficulties is that there are such large numbers of men exposed to fire. Sir Nathaniel Barnaby drew a picture of the effect of a shot, or a shell, which had passed through armour plating, but he did not give us the alternative. The alternative is, if you have not armour plating of some thickness, every little shell, every missile, almost every rifle shot, will have its effect upon the men. It is not a question that you can decide one way or the other. If you do not put a certain thickness of armour on to protect the men, the men will simply be struck by the smaller missiles that are fired. But if you put a certain thickness of armour to cover your men you will protect them from the smaller missiles although you will not protect them from the bigger missiles, but you will make sure that the bigger missiles will not strike you so often, because you compel your enemy to carry bigger guns: and, therefore, he has to carry fewer of them. Passing from that, I have only to make remarks upon one point which has been somewhat dwelt upon, and that is, as to the coal endurance of these ships. I cannot quite see how their coal endurance can be attacked. I think myself that we have ships in the Navy in which the coal endurance has been carried even further than necessary, which is a strong thing to say. But if one considers the duties these ships have to do, if I consider them from my point of view, as having commanded the sister vessel to one of the ships mentioned in the paper, in the Mediterranean, if I consider that in that ship I had less coal endurance than the new designs, and yet that never for one moment, no matter what the service I was sent upon, was I ever troubled in the slightest degree about the quantity of fuel on board, I cannot object to ships where there is rather more coal endurance than I possessed in a ship where I did not want any more. That seems to me, from my point of view, a conclusive argument that about 5,000 miles at ten knots is sufficient coal endurance. But I want to say, finally, that I believe the feeling of the service is entirely clear on the designs of these new battle-ships; that taking what the service asks for all round they are the fairest, the most open, and the most complete attempt to meet the Naval opinion of the day, which has ever been made by any naval architect since I entered the service.

Mr. J. H. Biles (Member of Council): My Lord and gentlemen, I feel a considerable amount of diffidence in attempting to take any part in a discussion upon what is so essentially a Naval question, but there is one point that I should like to raise. It has been been assumed all through this discussion that the best type of battle-ship is the ship with a belt. The discussion has really turned upon the question of the extent of that belt. The whole of Sir Edward Reed's objections to this design may be summed up, I think, by saying that the belt is not wide enough. If it is necessary to build a certain number of ships irrespective of the question of cost, there can be no doubt about it, this belt is not wide enough, because you can increase the fighting value of your ship irrespective of the question of cost by increasing her belt. If the question of cost is to be thrown over, as Captain FitzGerald wishes it to be, why should not we at once go to a ship of 25,000 tons displacement? If we wished to produce a moral effect, we could get a ship of that displacement, 450 ft. long, 90 ft. beam, and drawing from 30 ft. to 31 ft. of water. Probably the objection to draught of water might be got over by making the ship 510 ft. long, 100 ft. beam, and 27½ ft. draught, the same as in the new designs. One objection to increased size has been stated to be the reduced handiness. If we take

the handiness of vessels of the *Admiral* class as a standard, I think there is no insuperable difficulty in obtaining the same handiness in a ship between 450 ft. and 500 ft. long. The question of handiness has usually turned upon the question of length, but I think there has been rather a tendency to forget that you can increase the handiness of a vessel by increasing her rudder area, and if you wish the handiness equivalent to a standard vessel, say of the *Admiral* class, I do not see why you should not get the same handiness in a longer vessel, irrespective always of the question of cost. As a practical confirmation, to some extent, of that, I may state that a large vessel tried on the Clyde a few weeks ago, which has an abnormally large rudder area, a vessel over 500 ft. long, turned a circle in less than six minutes. That is a little more, I think, than the *Admiral* class, but it would only be necessary to increase that vessel's rudder area to give her the same handiness. But if the cost is limited, naturally we must see how we can get the best offensive and defensive powers out of our money. That of course is not, as Captain Fitzgerald says, a sailor's question when he gets on board a ship, but it is a sailor's question when he takes part in the deliberate negotiations on shore as to what is the best type of ship. Directly he gets on board ship, then is the time to forget about the cost. The question in all these ships, undoubtedly to my mind, is the armour; the weak point is the lower edge of the armour, and in my humble opinion I think it would be better on the whole to take off that 5-in. armour which is on the side of the ship which is 6 ft. 6 in. wide, and make it 15 in. thick, and a third of the present breadth; that is to say, that you could by taking the 5-in. armour off make the belt 2 ft. wider, and in that way, if you will have a belted ship, you would add to the fighting life of the ship; because, though one cannot, of course, take the authority of Sir Nathaniel Barnaby as completely establishing the fact as to a high explosive having got through 6-in. armour, one must believe that ultimately that will be attained, and then you will be exactly in the position that you were with the thin plating on the side just now. I think that for that reason, if you have weight for protection to spare, you should choose between whether you would add it to the breadth of the belt, or whether you would give it to your men, because, unless you are prepared to put five inches abreast of your guns on your maindeck, that is, the deck above the 5-in. belt as well as underneath, your men are just as likely to be damaged by shell fire, whether you have this armour under them or not. I do not know whether I make that point quite clear, but certainly, in my opinion, it would be more advantageous to the fighting qualities of the ship either to make that belt 2 ft. wider or to increase the protection round about the men. I should differ from Sir Edward Reed completely about this question of carrying up the height of armoured freeboard to the extent he wishes it, and for this reason. It appears to me to be obvious to anyone, when you consider what part of a ship you will protect, you must not only estimate the liability of that part to be hit, but you must also multiply that chance by the damage you will do when you are hitting that part. It must be obvious, I think, that if you fire a shot through immediately under the main deck, the amount of damage you can do to a ship must be very much less than if you fire that shot through immediately below the belt, and for that reason it seems to me that, considering the lower edge of the belt will be out of the water as often as the ship rolls down to within a foot or two of the main deck, and that the damage caused by penetration below the belt is so much greater than that caused by penetration above, the armour above the belt would be better bestowed by putting it underneath the belt than by putting it where it is, and for that reason it would be better to take this 5-in. armour off above, and put it down underneath in a narrower and thicker form. Still more is this so in the case of the *Nile* and *Trafalgar*, which have 12 or 14 in. armour ten feet above the water-line.

Captain C. Penrose FitzGerald: No.

Mr. J. H. Biles: Captain FitzGerald, I see, will dissent from that. There is one thing which I should like to say in connection with that. In a ship which has a complete period of ten seconds, the lower edge of the armour, as a consequence, would be exposed, perhaps, for one second in ten seconds; the part that is out of water above that armour is more likely to be hit, I think, than the part underneath in the ratio of about ten to one.

Captain C. Penrose FitzGerald: Fifty to one.

Mr. J. H. Biles: But the damage, if hit below the belt, would be a hundred times greater than if hit above. Therefore, it is more desirable to put the belt further underneath the water rather than to protect the part above the water, where the damage is not so great. My point is that you must estimate, in spreading the armour out, the amount of the damage likely to accrue from penetration, as well as liability to be hit. But, departing from the question of the belt, I suppose naval officers have made up their minds that this must be the type of ship. If you depart from that belt, and are disposed to have the inside armour, which I, for one, say is preferable, even in a ship like this, you can then take a sloped armour about ten inches thick inside, which armour need not necessarily be made as expensive as this; and on that basis, keeping the other conditions the same, you would very much reduce the cost of your ship, or you would attain what Sir Edward Reed says may be attained by competent persons, a ship which may steam 20 knots an hour, with her coal supply considerably added to; but the competent person who designs that ship must discard the outside armoured protection for the ship, and not add to it, as Sir Edward wishes. Only in this way can the extra speed and coal supply be got. As to the question of speed, there is one thing I would just like to say. I know of a vessel which has attained over 20 knots. I think she is the largest war-vessel in the world that has attained over 20 knots. She is under 5,000 tons displacement, and to attain that speed of 20 knots she required 11,000-horse power. The question of the relation of displacement to horse power, in the way Sir Edward Reed treated it, I think would not be borne out by that fact, taken in conjunction with another which I can give you, which is that a vessel of 12,000 tons displacement recently attained 20 knots an hour for a horse power of 14,000. That shows, I think, that the relationship of displacement to horse power cannot be taken account of in the way Sir Edward Reed has indicated. Such wide differences as these two, I think, require no further comment. I think there is nothing more I have to say. I thank the meeting for listening, but I think that this question of the side armour, though the Naval element has spoken against it, we have not heard the end of, and I am glad to see that Admiral Colomb and several others of the Naval profession are tending in the direction of internal armour.

Admiral Lord Clanwilliam, R.N. (Visitor): I will not detain the meeting two minutes. I only wish to add my testimony as a Naval officer to the general opinion throughout the service that these vessels are of the right sort, and that we have every confidence in the ability of the officers who gave the instructions to Mr. White to design them.

The President: Gentlemen, it is my duty to inform you I am compelled to call upon Mr. White for his reply, because the Society of Arts, who are the owners of this hall, want the hall to-night, and it has to be prepared by half-past five. I do not wish to curtail the discussion, but I am compelled by circumstances to tell you that.

Mr. W. H. White, F.R.S. (Vice-President): My Lords and gentlemen, the discussion has ranged over so large a field that it is not an easy matter, in the time during which I can claim your attention, to deal with the points that have been raised in anything like a satisfactory

manner; and I am sure you must all be most tired of hearing my voice. ("No.") I would like to begin by saying that it is a source of immense satisfaction to me to find that the discussion to-day has not justified a fear which Sir Edward Reed expressed in a letter to *The Times*, namely, that in reading the paper here I was appealing to a body largely composed of eagerly competing contractors for these ships.

Sir Edward Reed: It is because they have been silent on account of my drawing attention to that circumstance, and judiciously so.

Mr. W. H. White: I think, my Lord, that the explanation of Sir Edward Reed is not complete. It is like all that proceeds from him—apt, and to the point; but I do not think that, from the nature of the discussion, it was one in which the business members of the Institution—the shipbuilders and engineers—were likely to take much part. The points raised in the paper are almost entirely matters affecting what may be called the fighting efficiency of ships of war. We have had, I am glad to say, one speaker who certainly belongs to the class of contractors; but I think the meeting will endorse what I will add with reference to that speech, viz., that Mr. Biles has by no means justified the anticipation expressed in the passage which I read just now, because his remarks were largely critical. He thought it would have been better to take the armour from some portions of the new ships, and put it somewhere else. His views on armour protection are of interest to the Institution, but I will not discuss them now, simply remarking that he has missed one point in the paper of very great importance. I simply alluded to it, and can only now again allude to it, namely, that in the designing of these ships the protection of the guns and crews in the auxiliary armament has been most carefully considered and arranged for, in view of the complete experiments made upon the *Resistance*. The Admiralty consider that, in the public interest, it is better not as yet to make these experiments public property. Coming to the general features of the paper, I wish to point out one fact which may somewhat startle some gentlemen, but which is absolutely true. It is this: that in this paper, much as it has been supposed to add to the information given in the Parliamentary papers, the facts stated about the new ships are almost entirely those which appear in the Parliamentary papers, with very small amplifications on points of detail. This Institution has the enormous advantage of a membership which extends throughout the world. We have the advantage here to-day of the presence of gentlemen representing foreign navies, whom we are most delighted to see, and whose membership of this Institution is a great advantage to it; and I am sure that those gentlemen will not misunderstand me when I say that there are certain things about the new ships which I do not propose to tell them; and there are certain things about the ships which I do not think on any account should now be made public. I take it that the responsible authority in this matter is the Board of Admiralty. We have heard a great deal about the House of Commons. I wish to speak with all respect of that body, of its powers, and of its rights of criticism, but often when I sit under the gallery I feel that if I could have had ten minutes on the floor, I could have put matters in a different light. In some foreign legislative assemblies it is the custom for people whose work is being criticised to have the right of appearing to give explanations. Whatever may be the form in which that should be arranged, I think it would be infinitely better than to hear *ex parte* statements made, and passing unchallenged, whatever may be their source, or whatever view they may represent. Having said so much, without any intention of disrespect to the House of Commons, I will pass on to a few more specific matters. I want, first of all, to make it perfectly clear that, although I am the responsible designer of these ships, they are the ships of the Board of

Admiralty. It must not be supposed—and I want to emphasise this—that I approve personally of everything in these ships. It is not my business to approve or disapprove. It is my business to combine into the design the qualities and conditions as the Board of Admiralty, with such advice as the services behind it gives, says should be combined and embodied. It is my duty—a duty which I have fulfilled—which my honoured chief, the Comptroller, knows I have fulfilled, to put before the Board my views on every point, for their information and decision. When I have done that, my duty is discharged. But I come here to-day, not so much to justify myself as to explain what seem to me to be some misapprehensions as to what the Board intended, and what it was hoped would be achieved by these ships. That is the limit within which I work. Mr. Byles has referred to the question of inside oblique armour, as compared with side armour. That is a question which has been discussed here frequently, and a question which I hope we shall have the opportunity of discussing again on Sir Nathaniel Barnaby's paper to-morrow. That is a subject which, if I may venture to pass an opinion, for present purposes is of little interest, although undoubtedly important, *per se*. Now I should like to say a few words as to matters of fact in Sir Edward Reed's speech. I will preface these by stating that, although there has been hard hitting on both sides, there has been no want of good temper or good feeling in the matter. Nothing would be further from my wish than that a discussion, which ought to be scientific, calm, and dispassionate, should be degraded into anything like a personal duel or controversy. I have endeavoured in every way to avoid that. Sir Edward Reed referred to the *Nile* and *Trafalgar*, and I think he said that they had been spoiled. I believe that was the word he used.

Sir Edward Reed: I did not mean the ships had been spoiled. I distinctly took pains to say that they were better than intended. What I meant to say was altered——

Mr. W. H. White: And that Parliament knew not of these alterations.

Sir Edward Reed: Before this discussion.

Mr. W. H. White: As a matter of fact, in the Parliamentary papers it is distinctly pointed out, and the natural deduction is made from it, that in the building of the *Nile* and *Trafalgar* large additions have been made to their offensive and defensive power. We must take the ships, of course, for what they will be as completed. These additions have taken the form of extra protection to the sides of the central battery. The addition to the auxiliary armament was one of the many improvements in the equipment of the ships which the Comptroller made when superintendent of the dockyard at Portsmouth, and which added very greatly to the ships' efficiency. Such additions to weight make up the bulk of the 500 tons which have been added to the ship, so that the ships have been improved in their fighting capabilities by these additions, but draw more water than the Board of Admiralty say they wish any new ship to draw. That is the point. Having fully explained these facts, I was most particular all through the paper in every case to distinguish between the *Trafalgar* as designed and the *Trafalgar* as completed. I think that will appear if the paper is read again. Sir Edward Reed has had to read it hurriedly; his criticism suffers from that disadvantage. If he reads the paper again he will see that from first to last I have endeavoured always to say what the ship was intended to be, and what she will be as completed. As regards this matter of additions to ships during construction, and the "Board margin" which has now to be provided in new designs, all such additions belong to the history of the ship. It follows almost as a matter of course that as soon as a ship is laid down something will be added to her. It is a most curious circumstance that ultra-conservatism

prevails in many matters with regard to the equipment of ships. The order of events is this. As improvements or advances are made, it is customary to put in all preceding items, *plus* all modern improvements. Again and again I have suggested to the Naval authorities whether a step could not be taken in the direction of making a reduction in some articles of store or outfit, and something has been done in that direction, and is being done. But these are all minor matters as compared with this one great fact, that whether you like to complete a ship as designed or not, it is inevitable that when she goes on service she will get deeper in the water. Ships may get deeper in the water, as the *Admirals* did, and as the *Trafalgar* did, by having guns added to them, or the draught may be increased, as has been the case of the *Bellerophon*, which put to sea after twelve or fifteen years' service with her armour in anything but the position which was originally intended.

Sir Edward Reed: Will Mr. White allow me to say the *Bellerophon* given is from the legend which I brought from the Admiralty with me in 1870.

Mr. W. H. White: I did not in the least mean to question, and I hope Sir Edward Reed does not think I did question, the accuracy of his plotting down of the legend in diagram form. I do not raise that question at all. What I mean is this, that in the twenty years that have elapsed since that legend was prepared, the armament and the equipment of the *Bellerophon* have been altered and added to in such a way that she is very much deeper in the water now than she was then, and my point is this—this is what I wish to make out—that from the very nature of the case, from the progress of naval armament, ships will get deeper in the water. Take the *Minotaur* class. I gave the facts as to that class in a lecture I delivered at the Mansion House some time ago. It is only a question of where you will begin to date from. The additions will come. As to the Board margin now provided I will add a few remarks. It was seen that if a ship continued in service for any very considerable period after her construction, the additions made to her would be inevitable; and that considerable additions were often made during construction. It was therefore decided to provide a certain amount of unappropriated weight in all new designs, with the full assurance that use will ultimately be made of it. So far as the Board order goes, those considerations are, of course, complete and clear. But the naval architect's view of that matter often is different, and the additional load becomes a very formidable thing in working out a design. When I say that in a vessel like the *Blake*, which is to steam 22 knots an hour, we have to carry something like 350 tons of "Board margin," in addition to 1,500 tons of coal, it will be seen how increasingly difficult the problem is made by the additional load. The higher the speed the greater the influence on the design of the Board margin must be. I have endeavoured in the paper to explain that in the new ships with their high speed and very large loads, exclusive of the Board margin, the provision for that margin makes the ships still bigger, 520 tons of Board extra load having to be carried. Now we come to a question where I think there has been a little misapprehension. It seems to be thought that I credited the ships, as it were, twice over with the advantage of the Board margin. It will be found, however, when my paper is carefully read, that I have not done so. What I have pointed out is that if the ships are completed as designed (without additions), there will be the possibility of carrying 1,400 tons of coal instead of 900, and there will be the possibility of an increase in the coal endurance if that should be desired, or there will be the possibility of having the ships floating at a lighter draught, whichever may be thought desirable. The question of coal endurance is a perfectly distinct one. All my remarks upon the coal endurance of these vessels are based upon the 900 tons that have to be carried, and that are included in the load draught besides the 520 tons of margin. And I assert that these ships do compare favourably, as regards the coal endurance they will have with 900 tons, with ships like the

Devastation, *Thunderer*, and *Dreadnought*, which have been proved to have ample coal stowage by many years' working. We have heard of the *Thunderer's* experience to-day from Admiral Colomb, who commanded her. The *Devastation*, as designed by Sir Edward Reed, was intended to steam about 4,000 knots at 10 knots. As a matter of fact she can steam 4,700, which is 700 knots to the good. In the new ships, regard being had to the fact that all experience tends to prove the sufficiency of a coal endurance of 4,500 knots, 5,000 knots at 10 knots per hour have been provided. That is a matter the Board of Admiralty have decided upon, and on which their competence, I assume, should be accepted. If the *Trafalgar* takes in 1,200 tons, she will be immersed only six inches more, and equally it is true that these new ships can take in 1,200 tons with only six inches additional immersion. As to the speed question I cannot put the matter more clearly than it is put in the paper. What I say is that our investigations and model experiments have proved that for all practical purposes the *Trafalgar* and the new ships will be identical as regards the cost of propulsion up to speeds of about 16 knots. Above that speed the bigger and longer ship begins to gain on the other. The reasons for that advantage are patent enough, I think, to anyone who has examined closely the conditions of navigation at high speed. It is certain that all gentlemen here who have been working at the construction of high speed ships will agree that what I say is a fact as disclosed by the model experiments, is also a matter which could have been anticipated, and which we did anticipate in the design. The sheer draught of the ship, and our estimates for the power and speed, were necessarily made before any model experiments took place. The model experiments confirm our estimates, and add greatly to our information. With reference to the rough and ready mode of comparison which Sir Edward Reed adopted, whilst, of course, it is fair enough as a rough first approximation, it clearly is not one we should be prepared to trust for the preparation of a complete design. The greater length of a ship is a universally recognised advantage at high speeds. That is the simple explanation of the matter. Passing to the remarks that have been made on my reference to the *Dreadnought* having been re-designed, and particularly to the statements of Sir Edward Reed, I must insist on the acceptance of my statement, which is purely historical. I do not produce this fact for the purpose of causing any pain to Sir Edward Reed, I only mention that there was a ship designed in 1870 called the *Fury;* that every drawing in relation to that design was cancelled, and other drawings prepared which altered the under-water form of the ship, as well as her internal arrangements, and which resulted in the vessel known as the *Dreadnought*, built from an entirely new design. If the dimensions of the *Fury* and *Dreadnought* are looked at it will be seen that the extreme breadth of the ship was altered, and various changes were made. When we come to the question of what the new design involved, perhaps it will be as well to make a statement once for all which can be verified. I personally was intimately concerned with the reconstruction of the *Dreadnought*. I was at Pembroke detached from the Admiralty for many months in connection with that matter, and what I have to say is this, that the *Dreadnought* differs from the *Fury* in every feature of great importance, except the disposition of her armament. The armour is 14 inches thick instead of 12 inches; it is brought out at the side in the form of a citadel, instead of being on a narrow breastwork; the guns are worked on the hydraulic system of mounting, and are of another type of gun; and as regards machinery, she has inverted vertical cylinder compound engines, instead of horizontal low pressure steam engines. There was also an entire re-arrangement of the coal supply. The ship was re-designed throughout. It was a thing which would have had to be done in any case, owing to the adoption of the compound engines, and the improved performance of deep draught twin-screw ships. I pass from that, and had no wish to raise any discussion whatever upon the point, but it has been forced upon me. Then, as regards coal protection, to which Sir Edward Reed referred, I

think, in somewhat mistaken terms. I have myself quite lately had the pleasure of seeing what coal protection can do when attacked by high explosives—coal protection represented by such bunkers as we are fitting in actual ships. The results were of a nature altogether contrary to the views which Sir Edward Reed has expressed. Of course, the coal may not be there. We quite admit that. I was careful to say that in that case in the new ships we should have 5-in. steel as the minimum of protection. I am not going to express an opinion on the views which Sir Nathaniel Barnaby has given to the meeting, as to the 5-in. armour; whether that is the right thing or not, I do not propose to discuss. But as a matter of fact, and under all conditions, the presence of the 5-in. armour, plus this coal protection, makes an essential difference between the *Admiral* class and the new ships. Lord Charles Beresford referred to the *Admiral* class, and said he would be very pleased if someone would have the daring courage to fill the end of a vessel of that class with water, and see what she would do. I stand before you as the man who had the daring courage to do that some years ago. It has been done.

Captain C. Penrose FitzGerald, R.N.: The model, or the ship herself?

Mr. W. H. White: The ship herself. I will explain if you will allow me. I have no desire to leave the statement there. If reference is made to the paper, which I read here in 1886, on the steam trials of some of the latest ships, it will be found that in that year we had tried the *Collingwood* at light draught. We wanted to try one of the ships for designing purposes at deep draught. To do that we filled up the ship with water ballast; not merely over the ends, but in large spaces in the hold. The ship went out ballasted with water with her ends chock full, and she manœuvred and did everything quite satisfactorily, and quite justified the estimate which had been formed of her. The loss of speed due to filling the ends with water was only a quarter of a knot.

Captain Lord Charles Beresford, R.N.: May I ask whether you put 80 tons of water in the ship either forward or aft above the water belt, without filling in the lower part of the vessel at all, where the vessel would get wounded in action?

Mr. W. H. White: Yes; it was done in that way.

Captain Lord Charles Beresford, R.N.: Above the armoured deck?

Mr. W. H. White: Yes; the thing was quite full. We are not accustomed—we are such retiring people—to blazon forth to the world everything we do in that way; but the thing was done. It was not done for this purpose. It was done to bring the ship down to her draught, but the trial was made; that is the point.

Admiral Sir Geoffrey Hornby, R.N.: May I ask what would happen if you filled one end alone without filling both?

Mr. W. H. White: The ship would change trim. It is a calculable quantity. Now I come to the point which, I presume, is the pith of the whole matter.

Captain C. Penrose FitzGerald, R.N.: May I ask one question? I am sure you will excuse me. What would be the condition of the *Admiral* class, not the *Collingwood*, if she was treated in that way without putting heavy guns on her to balance her?

Mr. W. H. White : It would not be desirable, I think, to pursue this discussion. I will answer Captain FitzGerald as fairly as I can, but I want to make this statement as brief as possible because it has nothing to do with the paper. It has to do with the discussion of the *Admiral* class, and we do not desire to discuss the *Admiral* class to-day. But what was done was this. The *Howe* at that time had not her guns in ; but water, as I explained, was put in to represent the weight of guns, powder, &c., not on board. We did not want to stuff the ship with water simply for this purpose, or with ballast, but we did want to make a trial with water in her. Now I come to the question which I presume is the most important in the interests of this meeting, and that is the question of the disposition of armour, and I want to make a few remarks on that point. In my paper I was most careful in dealing with the system of isolated redoubts. I put it in this way : It might be urged that the system of separate redoubts should be associated with thicker side armour. That was done for the purposes of comparative designs. The association of side armour thicker than 5 in. with the separate redoubts was one of the things considered by the Board, and by them dismissed as undesirable in view of what was involved. In relation to the depth of armour below water I want to mention a fact or two. Although Sir Edward Reed very properly quotes a letter he wrote on April 4 to *The Times*, and, as I understood, published to-day, in his previous letter, which is dealt with in my paper, no allusion whatever was made to the depths of armour belts below water. I have looked carefully through the earlier correspondence and discussions, and I do not find the point brought out by him in any of them. I know perfectly well that the point was made in the House of Commons by a gallant officer, who, I hope, is present, Captain Bethell, in a discussion which took place last Monday week ; and, therefore, long before Sir Edward Reed wrote his letter published to-day. This point has been mentioned again and again in discussions of the kind, but I was perfectly fair to Sir Edward Reed in dealing with it in my paper, and I wished to be so. He had not in his letters, of which I knew, drawn attention to the point, and in discussing this matter, and in considering it, I had all along had in my mind the fact that ships are armoured to a small depth below water.

Sir Edward Reed : Would you just allow me to explain that the reason for that is that the deficiency of armour below water always improves with over immersion, but the deficiency of armour above water always gets worse with over immersion ?

Mr. W. H. White : This really does not touch the point I make in the paper, which is that the justification for shallow belts is to be found in the small vertical extension below water of the armour. But now I want to point out that if the table of belts of armour which is given with the paper is studied, it will be found that Sir Edward Reed himself has clearly, in other circumstances, been with the multitude who did evil in putting the shallow belt, and that he took the lead in reducing depth of belt below water. It was a fact I was not aware of when I had the table prepared so that we might see what the facts were, but I found that while in the *Bellerophon*, with 56 ft. beam, the belt went 5 ft. below water, in the *Devastation*, with 62 ft. beam, the belt only went 5 ft. below water.

Sir Edward Reed : She had not high sides, and could not be rolled the same as other ships.

Mr. W. H. White : That is a matter of opinion. In the *Fury* design of 1870 the armour was carried by Sir Edward Reed only 5 ft. below water, so that I feel that he has no ground for assuming the position of a critic in this matter. It must be admitted that armour going under water to a greater extent might, under some circumstances, be an advantage ; but I contend there is ample precedent for

saying that the new ships are not relatively badly off in this respect. In relation to the question of vertical extension of armour, I am one of those who altogether dissent from the view that the vertical extension of the armour below water is to be strictly proportionate to the beam, and I do it for good reasons. Actual observations show that when ships are running at speed in still water the wave profiles along their sides vary in position and vertical extent with varying speeds and forms of ships. As a matter of fact, the wave profile, in ships of moderate size, running at a good speed, causes a greater vertical displacement of the water below the still water than exists in larger ships; and of course that is a circumstance that must be taken into account, as well as the breadth of beam, when considering depth of armour. As I put it in the paper, there are many things which may expose the armour, and the true test, in my judgment, is not where we would like the armour to go, or where a diagram, such as Sir Edward Reed gives us, would show it to have gone, but what other people are doing, and whether we are facing only equal risks. As I pointed out when Sir Edward Reed was speaking, in one of his particular diagrams, which comprises the *Bellerophon* and the new battle-ships, the 5-in. armour on the new battle-ships is not shown. That 5-in. armour is to be of steel, and in portions of the *Bellerophon*, both before and abaft the battery, the corresponding iron armour is thinned down to 5-in. I merely wish to point out that it is not fair to have a diagram omitting the 5-in. steel armour which exists in the new ships, and giving prominence to 5-in. iron armour in another ship. My Lord, I feel I have trespassed too much on the indulgence of the Institution. I hope that the facts which have been brought forward and the discussion which has ensued will, at all events, satisfy the public on this point—that no pains have been spared to produce what may be regarded as, under present conditions, the most powerful war-ships which the Admiralty have ever ordered.

The President: Gentlemen, when I had the honour of addressing you a few hours ago, I ventured to express the opinion that I thought—nay, more, I believed—that the discussion which would arise on the paper would be conducted with complete fairness, and temper, and tact, and my expectations have been more than realised. I think you have had a most admirable discussion. It has taken a scientific turn. You have had the highest professional opinions upon these designs, and I hope you are all satisfied with the discussion. Many, I daresay, would have wished to address the meeting; but time is our old enemy, and everybody cannot speak on the same day. I am sure you will now allow me to convey to Mr. White, and to those gentlemen who have taken so important and leading a part in the discussion, your united thanks for their efforts. I have great pleasure in conveying that expression of your opinion to Mr. White.

THE PROTECTION OF BUOYANCY AND STABILITY IN SHIPS.

By Sir Nathaniel Barnaby, K.C.B., Vice-President.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 11th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

I have recently, in fulfilment of a long-standing engagement, prepared for another Institution a paper on "Armour for Ships; its Uses, and its Nature."

I did not discuss in that paper its uses for the purpose of protecting buoyancy and stability. Armour was not introduced for the purpose of protecting buoyancy and stability: it was introduced to limit the destructive effect of shell in the batteries.

It answered its purpose so effectively for the moment that artillerists gave up attempts to develop the shell, and directed all their efforts to obtain perforation of the armour by projectiles having no bursting charges. So armour was gradually reduced in area, and made thicker and stronger in such parts as were still supposed to need it.

Thirty years after the introduction into the French Navy of armour clothing against shells, that Navy is found with no armour clothing at all over the batteries of its largest ships. It has been nearly all concentrated upon a narrow belt at the water-line.

Artillerists have taken advantage of this condition of nudity, and have devised projectiles far more powerful than those against which armour was first employed, and they are once more making existence in the batteries for guns and men impossible.

Fig. 1 (Plate XXVI.) shows, not an actual target, but a representation of what happens to the heavy beams, and the plating upon them, when 70 lbs. to 80 lbs. of a high explosive is detonated between decks.

The French have been so impressed by their experiments with high explosive shells that they have reverted to side armour, to prevent the admission of such shells between decks, under the guns and gunners.

The changes of fashion as to side armour in France are shown in Table 1 and Fig. 2.

The Admiralty, in the 14,000-ton ships just proposed by them, have thought it necessary to guard the positions of the heavy guns against the explosion of such shells beneath their floors, and also to guard the deck space under four out of the ten 6-inch guns, by armour 5 inches thick.

TABLE I.—Phases of Armour.

1st Period. Floating Batteries. 1854-58.

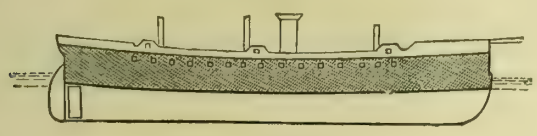
2nd Period. 1858—1868.

Gloire.

1858. 1st phase.

Armour (side) $4\frac{3}{4}$ inches.	5,500 tons. Speed, $12\frac{3}{4}$ knots.	Percentage of weight devoted to armour, 15.

Fig. 2.

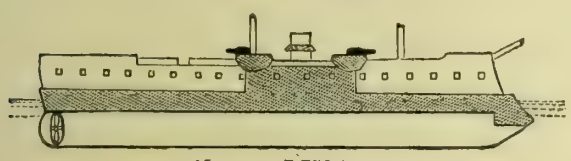


Gloire, 5,500 tons.

Marengo.

1869. 2nd phase.

Armour (side) $7\frac{3}{4}$ inches.	7,750 tons. Speed, $13\frac{1}{2}$ knots.	Percentage of weight devoted to armour, 17.

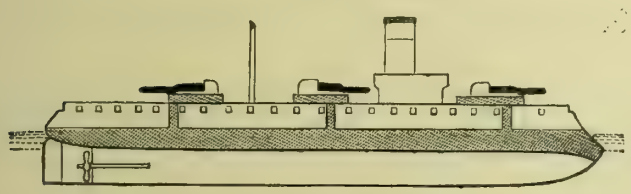


Marengo, 7,750 tons.

Baudin.

1880. 3rd phase.

Armour (side), &c. 22 inches.	11,200 tons. Speed, 15 knots.	Percentage of weight devoted to armour, 33.

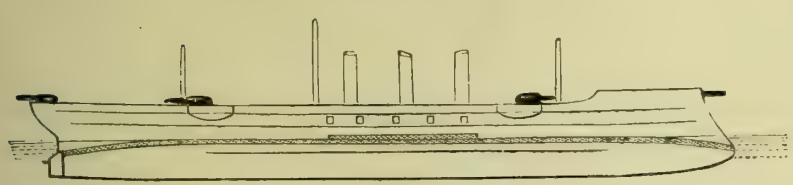


Amiral Baudin, 11,200 tons.

Tage.

1886. 4th phase.

Armour (deck) 3 inches.	7,000 tons. Speed, 19 knots.	Percentage of weight devoted to armour, 14.

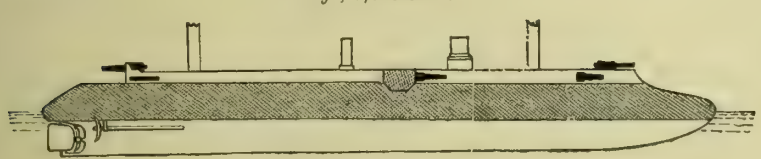


Tage, 7,000 tons.

Dupuy de Lôme.

1888. Return to 1st phase.

Armour (side) 4 inches.	6,300 tons. Speed, 20 knots.	Percentage of weight devoted to armour, 15.



Dupuy de Lome, 6,300 tons.

I do not discuss here the advisability of employing such thin armour. I have done that in the other paper referred to, when considering the French action in the matter: I would only remark that 5-inch steel armour is penetrable at 1,000 yards by the 5-inch gun, and will allow common shell to pass through whole, to explode between decks.

When that paper was prepared I had had no information as to what the Admiralty proposals were likely to be.

I now see that in order to give this protection, and to protect more of the buoyancy and stability by side armour, the cost of ships of the type of the *Admiral* class is to be increased by about one-third.

Comparing the three new ships of the barbette type with the *Admiral* class, it may be seen that the armament, speed, maximum thickness of armour, the fuel supply, and the protection against the ram and the torpedo are the same, but the displacement is increased from 10,550 tons to 14,000 tons, which is an increase of one-third, and must represent, other things being equal, an increase in expenditure of a quarter of million of money for each ship.

As each of these four ships must cost at least one-third more than each *Admiral*, built under the same conditions, we lose more than one such ship for our money in making the changes in the *Admiral* type in four ships.

I have myself been studying the alteration in conditions introduced by the high explosive shell and the rapid-firing guns, to which we owe this extension of armour abroad and at home, and I place upon the walls the design of a ship prepared by the Naval Construction and Armaments Company under my advice (Plate XXIV.).

She is intended to have the same speed as the larger Admiralty design, *i.e.*, two knots more than the largest French ships; and to be capable of perforating more than 99 per cent. of the area of the sides of all armoured foreign ships. She would be unable to perforate the thick armour covering the remaining one per cent. of the total area, and much of this one per cent. will be impenetrable to the guns of the 14,000-ton ships.

The 67-ton gun, with which the 14,000-ton ships are to be armed, is incapable of penetrating the thicker belt armour of the French ships.

The small design prepared at Barrow gives protection to magazines and machinery by a steel deck throughout; to the armament, by armour about equal to the most powerful of the quick-firing guns (the 6-in.), and proof for the present to the high explosive shells. It gives the greatest protection of all, by double armour, to the fighting station for the officers who direct the ship, and point and fire the guns and the torpedoes. It proposes to protect the buoyancy and stability for the first time by a solid raft.

I now only call attention to the curious fact that while this design, intended to meet the new conditions, has been in course of preparation, the Admiralty have taken their course, and they add the precise cost of the Barrow ship, with its armament and outfit, to the cost per ship of the *Admiral* type, in order to strengthen the armour in that type, in four new ships.

In other words, for the four of the new Admiralty ships we might have five *Admirals* and one of the protected Barrow ships, or four *Admirals* and four of the protected Barrow ships.

But the Barrow type has such thin armour, you will say. A single well-planted shot from a heavy gun may pierce and shatter the wall which protects the guns. Quite true; and, recognising this, the designers put the cost of the Admiralty 17-knot ship into five ships, with five such batteries. And the designers of the Barrow ship make the same reply as to all the risks incidental to warfare at sea. But what of the 14,000-ton ships? Some of us have read the very clever sketch of a naval engagement, entitled "In a Conning Tower," appearing in the last July number of *Murray's Magazine*. The sudden destruction of the large French ship by the ram is not an unfair picture of what may happen to even a 14,000-ton ship.

It would have been easy to imagine similar horrors from a successful torpedo attack. There is no attempt to remedy this weakness in the new large ships.

Then the entire central battery on both decks in these new ships is open, as I understand it, to quick-firing guns and high explosives, and is without any armour protection against them. It may be noted also that in these ships of 75 feet in width the armour belt is to extend only $5\frac{1}{2}$ feet under water. An inclination of the ship of 10°, or the pitching and 'scending and heaving in the sea, would expose the bottom plating below the belt. Will not the quick-firing guns find out this weakness? Penetration below the belt or through the belt means immediate serious disaster; penetration above the belt or above a protecting deck, about which so much is apprehended, can only lead to disaster by an accumulation of effective damaging blows.

So we say we are so sensible of the necessary weaknesses in defence, in the best-designed ships, were we even to go to 14,000 tons, that we prefer for the same expenditure of money to give ourselves five chances instead of one.

You may also consider the attack weak in the small ship. They are one knot slower than the large Italian ironclads, which may by some grave misfortune be in the hands of an enemy. But they are as fast as the 14,000-ton ships are to be, and they may be made two knots faster by taking the proportion of four to one instead of five to one.

If you say the armour-piercing guns are few, I should demur to that. I should say that we have ten heavy guns, against the four of the 14,000-ton ships.

And as to the power of these guns. They are more powerful than the guns of the *Dreadnought*. There are no completed ships in the British Navy carrying such powerful guns, except the twenty-two recent ships designed chiefly under the

administration of Lord Northbrook, and which have been selected for public animadversion because in them side armour has been calmly, thoughtfully, and, as I hold, wisely reduced.

The guns proposed for this 3,200-ton ship are estimated to be capable of perforating 18¾ inches of iron armour at 1,000 yards.

There are lighter guns in the armament for defence against boat attack, but they would not be manned in a general engagement. Two of the 6-pounder quick-firing would then be mounted between the heavy guns, under cover of the armour.

I wish now to consider particularly, and very briefly, the question of the protection of buoyancy and stability.

I have given my illustrations of the changes in armour from French ships, and I now propose to see what the French have done as to protecting buoyancy and stability in their fighting ships.

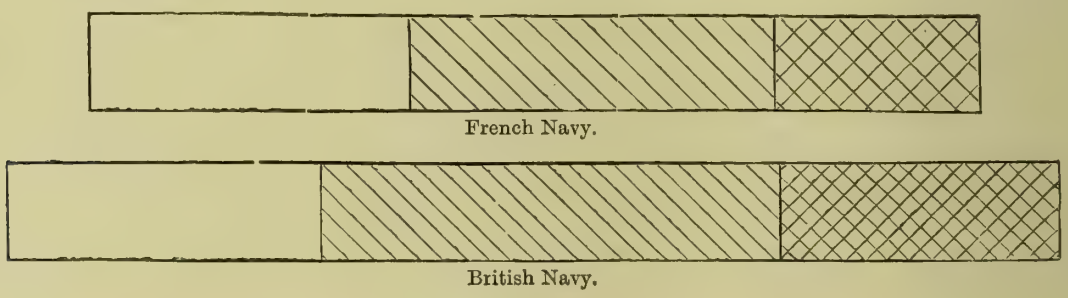


FIG. 3.

Fig. 3 is a graphic representation of the numbers of fighting ships of 1,000 tons displacement and upwards, built and building.

Scale—30 ships to one inch.

Dark shading.—Ships having some armour not less than nine inches thick, for protecting buoyancy and stability.

Light shading.—Ships protected by armour, but having none as thick as nine inches for protecting buoyancy and stability.

No shading.—Unprotected ships.

I have taken all the fighting ships of 1,000 tons displacement and upwards in the French and British Navies, built and building, and I find that in the French Navy there are about 138.

Of these 31 are protected by water-line armour, not easily penetrable, throughout the whole length of the ship, by the 100-pounder quick-firing gun at 2,000 yards; in other words, the armour in these 31 ships is in some places as thick as 9 inches. One hundred and seven of the ships are easily penetrable by this gun everywhere; and of this number 50 are without any protection by armour, either horizontal or vertical.

Let us realise what this means. The French will send into action 10,000 men in

50 ships, in which ships there are boilers and magazines accessible to the lightest quick-firing gun, and there is nothing to prevent a projectile from traversing the ship and driving out the bottom plating under water on the further side of the ship.

It will not need many minutes to put an end to an action between such antagonists. And if those ships are added which have no side armour so thick as 9 inches, then we get more than *three-fourths of the French Navy with no efficient protection of buoyancy or stability by means of side armour*. I do not say that our own ships are very much better. They are better, and the diagram represents fairly how much better.

What I desire to draw attention to is the entire absence of any attempt to improve the condition of the 10,000 to 12,000 of our own men in our own unprotected ships. No one gives a thought to them when the perils of insufficient armour in some heavily armoured monster are descanted upon.

We have built, and are building, about 120 ships, of 1,000 tons displacement and upwards, with crews of something under 30,000 men, having no armour as thick as 9 inches, and such side armour as there is would be of iron.

The 43 ships having some side armour as thick as 9 inches, for protecting buoyancy and stability, will not accommodate more than 20,000 men.

Taken altogether, there is not fighting accommodation in the whole of these British fighting ships of 1,000 tons displacement and upwards, protected and unprotected, built and building, for 50,000 men. Fifty thousand men only, while in our last naval war we had 146,000 seamen and marines borne upon ships' books. We may be sure that the very first effort, in a serious war, would be to find ships and guns for another 50,000. But what ships, and what guns ?

Confining our attention to the ships, we see at once what they must be. They must be ships without any armour. And yet we are to strain every nerve to increase the already monstrous armour protection for four ships' companies of 500 men each.

In order to give more protection to each of these ships' companies, and to raise the armour per man from seven tons to ten tons, as compared with the ships' companies in the *Admiral* class, where there is seven tons of armour protection per man, we are to be willing to give up an additional 17-knots armoured fighting ship.

For 2,000 men in four ships, each man covered by ten tons of armour, we are to be willing to give up 2,000 men in four equally good ships of the *Admiral* class, except that each man has only seven tons of armour; together with 600 men in four ships of the same speed, each man covered by $4\frac{3}{4}$ tons of armour.

The principle on which I and my former colleagues sought to work, during many years past, was that every fighting ship ought to be protected against sudden destruction by the single blow of an adversary's guns. We further did our very best to improve the fighting efficiency of that auxiliary navy which has no armour; which we found, nearly universally, without any efficient bulkhead divisions; and in which we should have to send to sea immediately, at least as many armed men as could embark in our regular ships.

As to the principle of the design of a fighting ship, the late Council of Construction agreed to this, and it guided their work. They said in a good fighting ship there should be the greatest possible offensive power; and the defensive arrangements should be such as to give security as far as possible, and in equal degrees, against all the various modes by which the ship may be disabled or destroyed.

They said that it followed from this that it should not be in the power of the enemy to disable the ship by one single blow, delivered by any means at his command, if this could have been prevented by causing other defences, where he has not this power, to surrender a portion of their strength to succour the weak part.

When they did not employ armour on the sides, they defended the vital parts by a bomb-proof deck, so that the ship should be protected against sudden foundering or explosion. When they employed side armour they made it as thick as possible over the vitals, *i.e.*, over the parts, injury to which might lead to immediately fatal results. Where injury could not cause such immediately fatal results, they made such parts surrender their defence in favour of the parts which were vital.

The French have acted otherwise. They have denuded their batteries of armour in order to cover parts of the water-line which need not have been vital, but which they have deliberately made so. They now find that the melinite shell dismounts their guns, and makes their batteries untenable, and they are hastily covering the topsides with armour in new ships; in which respect, I think, they are quite as unwise.

Let us pursue a little further the question of the principle on which all the English ships have been constructed for many years past, from the *Admiral* class down to the gun-vessels. If there is any other sound principle for judging of the fitness of designs, I have yet to learn it.

The critics of the ships find it easy enough to point out and dilate upon short-comings in any ship which has been limited in size with a view to reduce the cost. Each one of its powers stops short of what would be attainable were the others sacrificed to it. We have seen how the improved armour defence, mainly for buoyancy and stability, has raised the cost of the *Admiral* class by one-third, and has yet failed to secure the approval of those who choose to concentrate all their attention upon this

one secondary quality. I say it is secondary; because, if it were of primary importance, we should have no seagoing ships sent into action without such defence. We are told, on the highest Naval authority, that the heavy armoured ships will be accompanied, on all occasions, by a considerable number of unarmoured ships, for the purpose of flanking and supporting the heavy ships against attacks which would be perilous to them. This means that the unarmoured ships will have to give and receive blows, and I presume that there will be no rule that an armoured ship must not strike one that is not armoured; and I cannot conceive that the "battle-ship," which is to be so exceptionally treated in armour defences, is to be the only class of fighting ship which the enemy will endeavour to destroy by artillery fire.

I contend that the distinction in respect of protection which is set up between battle-ships and other ships is a novel one, and a most dangerous one.

Before the days of armour plating every ship was treated, so far her defensive power was concerned, in the same manner. They all ran equal chances. They differed only in the power of attack. And it is the more necessary to adhere to this principle seeing that, according to our most distinguished sailors, large and small ships will be associated in action more closely than ever.

But our practice is that the larger proportion of these ships are to be protected by an office classification, and are supposed to need no thick side armour nor deck armour either for the defence of the buoyancy and stability against the gun; while a smaller number, classified in a different manner, are to have so much defence that we can put only a mere handful of men and guns afloat, because the money has to be spent upon this exceptional and monstrous protection for a few ships. Each one of these four new Admiralty ships is to have 5,000 tons of armour, at a cost for mere armour plating of not less than £400,000 for each ship.

Let us apply the principle of design which I have put forward, not to a single ship, but to a given expenditure of money for fighting ships.

Let us suppose we have from a million to a million and a quarter of money to spend in order to put from 500 to 600 men afloat in fighting condition.

We may have either one ship or five.

		1 Ship.		5 Ships.	
Displacement	tons	14,000	.....	16,000	
Speed	knots	17	.....	17	
Heavy protected guns		4	.....	10	less powerful.
Gun positions protected by armour ...		2	.....	5	not so well protected.
Rams		1	.....	5	not so powerful.
Torpedo discharge		1	... ..	5	
Officers in command		1	.....	5	

Let us now apply the principle. There should be the greatest possible offensive power; and the defensive arrangements should be such as to give security, as far as possible, and in equal degrees, against all the various modes by which the money expended, and the men engaged, may be destroyed, or rendered useless.

Does the single ship give the greatest possible offensive power for the money and the 600 men? Does the investment in one ship give as much security against destruction by the ram, the torpedo, the gun, or by the perils of the sea, as is given by the five ships? If you say, why not carry the principle further still, and make more than five ships with your money and men? I answer that we are stopped by the consideration that the single ship must be large enough to engage in battle whenever and wherever the adversary can fight. It must have a speed equal to that of the ships it may be required to meet in war, and it must itself be fairly secured against being disabled or destroyed by a single blow. The single ship, therefore, needs water-line protection; defence for her gun positions against quick-firing guns, and high explosive shells; and defence of her brain power.

A smaller ship than that which I have described would not do this. All the conditions enumerated are reduced to a minimum in the ship of 3,200 tons.

I propose now to deal with the substitute for side armour for the water-line protection which has been adopted in the ship of 3,200 tons.

It will be within your recollection that a Committee on Designs sat in 1871, and included among its members six eminent Naval officers, among them the present First Sea Lord of the Admiralty.

This Committee directed attention to the desirability of getting reserve of buoyancy by other means than armour plating.

They thought that "the ship might consist of a plated central citadel, surrounded and supported by an unarmoured raft, constructed on a cellular system, or containing some buoyant substance, such as cork, which, without offering any material resistance to the passage of projectiles, would not be deprived of its buoyancy by penetration."

The late Council of Construction directed its attention to this for years, and devised indiarubber bags, thin metallic boxes, and various other arrangements for securing this object. But we could never satisfy ourselves. The risk of the collapse of a considerable number of these empty vessels by one shock seemed to us to be very serious.

While, therefore, we proceeded, as far as we could, with a raft body for the ends of the ships, we employed solid substances in those ends for excluding water there. We used cork enclosed in small water-tight chambers; the ship's stores; and spare fuel. We

used these defences against the invasion of water as supplementary to the armoured middle of the water zone; and we made that armoured middle only so long as was required to enclose the machinery spaces and the communication between the magazines and the armoured batteries.

It is that system which has been so severely criticised. In my judgment it is the right system; and what we have seen to be the cost of an extension of the armour, appears to me to strengthen the position of the designers of the *Admiral* class.

But when we came to consider a design for a sea-going fighting vessel of minimum size and cost, it was obvious that belt armour could not be admitted at all. There were several devices which had been adopted for small war-ships. There was the Armstrong plan, with wings of cork upon a submerged deck. There was the French plan of cellulose dams. These dams act by the expansion of the compressed cellulose (cocoa-nut fibre) when exposed to the water, as it seeks to pass through a shot-hole in the dam. But this cellulose washes out easily if the hole is large; and it is not to be trusted. I considered that what we needed was a light, non-absorbent solid. I put the problem to the staff of the Naval Construction and Armaments Company; but they could make nothing of it. I found that the Woodite Company were making a porous indiarubber, which would answer admirably for a solid packing. There was nothing against it except that it cost £450 per ton.

I then submitted some of this Woodite material to an eminent chemist, and asked him whether a material could be manufactured possessing the qualities of lightness (not exceeding in weight 22½ lbs. to the cubic foot) and non-absorbency of water, at a price, for large quantities, of £50 per ton. My chemical friend could not help in the matter, but he recommended an appeal, by way of advertisement, to the chemical profession. Captain Wood then undertook to produce such a material as we were seeking.

He has succeeded so well that he produces the material at so low a weight as 10 lbs. to the cubic foot, and with so low an absorbent power that it excludes 96 per cent. of water, for 24 hours, from a packed compartment.* It is slowly inflammable, and it is inelastic. It would be better if it were uninflammable and somewhat elastic. But I consider that the material, in its present early stage of manufacture, may be used confidently in the way proposed.

The submerged deck is covered by numerous partitions of thin steel, about one-sixteenth of an inch thick, and these partitions are left uncaulked. The partitions rise to some height above water agreed upon, and the compartments are filled in solidly.

* It appears that this very low absorbent power cannot be had at present concurrently with so light a weight as 10 lbs. to the cubic foot. Lightness and non-permeability to water when injured are still to some extent alternative qualities.

Upon the upper edges of these thin steel partitions rests a thin steel plating, not caulked, and not fitted in a water-tight manner. Water may pass down into interstices left in the packed spaces without any disadvantage that I can see.

The present price of the packing material, or "wood armour," is £45 per ton. Taking its average weight at 13 lbs. to the cubic foot, we should get 157 cubic feet of space occupied solidly for £45 worth of material.

The amount used in the Barrow design is between 4 and 5 per cent. of the displacement. It is 18 inches deep in the shallowest place, and 6 feet deep at the sides, where the stability wings are formed. These wings are enclosed in thin steel cases, and extend two-thirds of the length of the ship. The cost of the packing is in this case, at the price named, £6,000 for the ship.

The material is doubtless susceptible of improvement. I put it before you as being already suitable for our purposes.

I consider that the design in which it has been adopted is in complete accordance with the recommendation of the Committee of 1871, and meets the requirements and needs of England to-day.

The material has the advantage, which side armour has not, that it is applicable to all fighting ships, large and small.

A solid raft, formed upon and above a deck covering the machinery and magazines, and occupying the water zone, is what is wanted in every fighting ship.

I hope that this method of protection may come into use, because it will enable us to give once more reasonable security against foundering, under artillery fire, to all fighting ships. It will allow us to devote some armour to protect the batteries against the attack of the high explosive shell and the quick-firing gun. The present defencelessness of the batteries is no longer tolerable. It will give us both these advantages, consistently with a large increase in the number of ships, and in the power of putting fighting men afloat.

DISCUSSION.

Admiral Sir John D. Hay, G.C.B., D.C.L., F.R.S. (Vice-President): Lord Ravensworth and gentlemen, I wish to offer a few observations, with your permission, upon this paper, and, incidentally, upon the important subject which was under discussion yesterday, which, I understand, may be touched upon so far as it bears upon this paper. I agree with Sir Nathaniel Barnaby in so far as he has stated that five small ships can be found which are as swift, which contain all the appliances of war, and are as safe, that probably the money would be better spent upon them; but I doubt very much whether that as yet is possible. The material which Sir N. Barnaby has introduced to the notice of the meeting,

which I believe is appreciated by those who have seen something of it, is not yet generally known, and I cannot conceive that the Admiralty would be justified at this present moment, when the protection of the country requires the immediate construction of a number of vessels, in going into a new system with a new material which has not been thoroughly tested. I agree with what fell from my gallant friend the Admiral of the Fleet, Sir Geoffrey Hornby, yesterday, that concentration is of the greatest value. I think it is desirable to concentrate your forces in one ship, and the large ship has this advantage, that it is a base of operations for the smaller ones. It is the magazine which contains all the material of war for the supply of the smaller vessels, and it probably has the advantages of speed and coal endurance and other advantages which are only to be obtained in the large ship in superiority to the small ones. The paper which we have heard to-day states that there are five chances to one in favour of the smaller vessels as against the proposal which has been put forward by the Chief Constructor. Well, these five chances to one are the five chances that one of the five will be sunk and that the other four will be damaged, and I think it possible that the larger ironclad battle-ship, if properly handled and protected, might have the same advantage over these small vessels that the old line-of-battle ship had over numerous gunboats and other methods of attack. The *Italia* has been alluded to, and, incidentally to the *Italia*, I must say I regret exceedingly that it did not appear in the interesting information we obtained yesterday from Mr. White that the speed of the *Italia* was to be eclipsed by the new vessels which are about to be built. I agree with many of the naval officers who spoke yesterday that the first quality of a great ship should be, after sea-worthiness, speed. That comes before protection or armament, or anything, both for applying the ram and for the avoidance of its attack. I think that being able to choose your position with reference to your enemy is of greater consequence than almost any other qualifications in the ship. In the *Italia* you have a ship, though imperfectly defended, as I think, considering the great amount of money spent upon her and her great tonnage, with four 100-ton guns firing in a line with the keel, so as to offer the smallest target, while at the same time you have the concentration of the nearest fire, there being four 100-ton guns directed on that line. That ship can choose her position with this very heavy battery with the greatest possible impunity from the point of view of making herself the very smallest target. She has, however, this disadvantage, that, her water line not being protected, she is liable to be destroyed or damaged in that direction. What does that point out to us? It points out that we ought to obtain, if possible, the battery power and the speed of the *Italia*, and we ought to obtain some additional protection in the most vulnerable points, which are, in my opinion, the extremities rather than the broadside. With turret ships, or with ships which are intended to be used for ramming or for end-on fire, the bow and stern are of more consequence to protect than the broadside, in my opinion. It seems that the old desire to consider the broadside as the part of the ship which is to deliver the fire induces naval architects still to put the protection in that direction, rather than in the more vulnerable part of the ship. Now, I would with great deference to Mr. White, whom I see here, ask whether it would not be possible to gain the additional buoyancy which would be necessary for a narrow all-round belt, say of 8 ft., by lengthening the ship by 15 ft. or 20 ft., which, with the present power, as I understand, would not require larger engines to give the additional speed, and might possibly increase the speed, as I understand, up to the point which is required to compete with the *Italia*. I venture to make that suggestion, because my gallant friend the Admiral of the Fleet—I am not sure whether Sir Geoffrey Hornby is here—observed yesterday that there was no defect in these ships by reason of increasing the length a certain proportion larger than the previous ships of the *Admiral* class, and yet that the *Minotaur*, and the *Northumberland*, and the *Agincourt*, which were 430 ft. long if I remember right——

Mr. W. H. White, F.R.S.: Four hundred feet.

Admiral Sir J. D. Hay: Were of an excessive length. But as far as I have read the reports recently, coupled with such experience as I have seen, the *Northumberland* and the *Agincourt* and the *Minotaur* are very handy ships and very good sea vessels, and I cannot understand why there would be any great difficulty in lengthening the vessels which are now about to be built, if the advantages which I have suggested could be obtained in addition to the belt round the bow, which, I venture to assert in these days of ramming and end-on fire, is the most delicate part of the ship, and the part which is most liable to injury. With reference to the design under discussion, I am not quite sure whether the safety of the funnel is ensured by the arrangement which is made. I have not had the advantage of seeing the Barrow design, and, therefore, I cannot speak with any certainty, but I am not quite sure that the arrangement made is the best, though I have no doubt that Sir Nathaniel Barnaby is right. I think that under vertical fire, possibly directed to that part of the ship, there would be liability to injury in a double degree, both as regarded the engines and as regarded the artillery. There is another question with reference to the design as to which I should like to hear an exposition. With reference to the eight ships which are now undertaken by Parliament, I should like to hear some expression of opinion from an authoritative source. One ship is to be a turret ship and the other ships are to be barbette ships. One must be a better design than the other. In my opinion the turret ship is the better of the two. It appears to me from a note in the Parliamentary paper from which I quote, that Sir Arthur Hood concurred in that. At any rate, I am sorry that the most able officers, on whose skill and judgment I should be most delighted to rely, have not spoken with perfect unanimity as to the kind of ship, or the manner in which the guns should be placed in the ship. I have not a doubt myself that the turret is the better plan of protecting the guns. I understand that the majority of the new ships are to be built on the barbette principle. It may be right that they should be built barbette. The barbette may be better than the turret, but one or the other is better, and let us have the better of the two. I do not put forward my opinion against it, but I do not see why we should have a variety when they are not for different services. Experienced officers certainly ought to be able to give a judgment with no uncertain sound on this particular point. Sir Nathaniel Barnaby has very properly pointed out, as I think, to the meeting the fact that probably we should require some additional ships for 50,000 men at a moment's notice if we were at this moment to go to war. That is to say that we have plenty of men, but not plenty of officers, and that we should not have the opportunity of using them even if the ships were built, which Mr. White and the Admiralty have recently designed, and are about to complete. Indeed, I believe there is no doubt, and in that I know that my gallant friend the Admiral of the Fleet agrees with me, that a very large addition is necessary for the Navy beyond that which is now proposed; and I myself, looking to the condition of other countries, think we are not safe without seventy first-class battle-ships, that is to say, thirty-four in addition to what we have now, or twenty-four in addition to those which are about to be built; but we are not likely to get them. If the Barrow design is the best class of second-class armour-clad, by all means let us have it, but do not let us have it instead of the first-class battle-ships, which I think, and I believe this meeting thinks, are necessary for our protection. Sir Nathaniel Barnaby drew an illustration several times, which I do not quite agree in. I agree entirely with what he said with reference to the fact that armour was originally introduced to protect wooden-sided ships from shell-fire. That no doubt was its original inception. The first historical statement is perfectly accurate. The protection of wooden ships from shell-fire having been made entirely complete as against spherical shells, the artillerist eventually compelled us to thicken the armour, and then when the ship would not carry it, to place the armour over the vital parts of the ship, and to leave the rest unprotected, but I believe the protection ought to be complete where you protect at all; that there ought not to be imperfect protection; that you should protect the water-line, amongst other

things, where it is exposed to fire, and I say so because it appears to me without reference to the question of the rolling of the ship, and the question of her occasionally exposing other parts, that a vessel usually being fought on an even keel, that under rapid fire from quick-firing guns, a series of punches might be applied to the water-line of the ship, which would render her sinkable, or would certainly soon make her defenceless. It is for that reason among others I think that a narrow belt on the water-line and all round is absolutely essential to a perfect battle-ship. The protection for the magazines, the protection for the machinery, the protection for the guns, the protection for the steering gear, are all very valuable, and they should be complete, and where you cannot completely protect, I think it is best to let the shot go through, or even the shell; let them pass through and damage the persons beyond it. The point upon which I differed with Sir Nathaniel Barnaby was this. He said that before the days of armour plating every ship was treated, so far as her defensive power was concerned, in the same manner; they all ran equal chances; but I hardly think that is an accurate statement. The line-of-battle ship scantling was very different from the scantling of the frigate; and that of the frigate from the corvette and smaller vessels. In the beginning of all things, as you may read in Pittscottie, the *Great Michael* in Scotland was built from wood from Falkland forest, and none of the artillery of that day could penetrate her sides. She was a very large ship of her kind, and although that was not continued always, the line-of-battle ship could always take a great deal more hammering than the smaller vessels, and it was always considered right and proper that they should expose themselves to heavier fire and to greater risks in consequence of the fact that they were so built as not to run equal chances with the smaller ships, but be able to take a great deal more punishment than a smaller ship ever could do. Therefore, I differ from Sir Nathaniel Barnaby in that point in his paper. For the same reason, I think your ship should be made as strong as possible; as strongly offensive as possible by all means, and as strongly defensive as you can. I am sorry to say that but little has been done as yet, as I understand, to protect from the torpedo. That is a danger which still remains. I do not know whether the skill of those entrusted with these duties will eventually give us a ship as safe under water as a ship above, or whether we shall eventually have an honourable understanding among nations that we are not to strike "below the belt," but I am afraid that is hardly likely to come about, and, therefore, so long as that danger remains a ship must be liable to be sunk in action. We cannot make her safety absolutely certain, but we can give her the most offensive powers in the world if we give her great speed and protection in those parts in which she is most liable to be attacked by quick-firing guns or by heavy artillery.

Captain S. Long, R.N. (Associate): My Lord and gentlemen, there is one aspect of this question to which I should like to call attention. I think that Sir Nathaniel Barnaby is doing us all good service by calling attention to the very unprotected state of our unarmoured ships; but I would observe, and more especially with a view to what fell from the Admiral of the Fleet, Sir Geoffrey Hornby, yesterday as to the importance of large ships, that I believe that a large ship is a good ship in the same way that it is a maxim in fortification that a large place is a good place. We hear that Sir N. Barnaby's ships are to go at 17 knots. We also hear that the new battle-ships are to go at 17 knots; but I think we should not lose sight of the fact that if a ship of 14,000 tons goes at 17 knots, and a ship of 3,000 tons goes at 17 knots, it implies a very different thing. Directly the waves get up the large ship will continue to go at 17 knots, but the small ship will stop, and I think that is an aspect of the question which should not be lost sight of. The only other point upon which I would take up the time of the meeting is with regard to the high freeboard forward of the new ships, which is an interesting question. I notice in Plate IX. that the lower part of the freeboard forward is divided up into small spaces. I was very glad to see that, but I would remark that the height of freeboard which is

necessary* is a very important question, and one upon which, I think, experiments might throw a good deal of light. It will be observed that one of these ships if she pitches four degrees will put about 13 ft. down under water, and of course there would be very little left above water. She is 18 ft. forward out of the water. That would leave 5 ft. Anyone who has read the account published in Sir Thomas (now Lord) Brassey's book, "The British Navy, 1882," describing the trial of the *Devastation*, in company with the *Sultan* and the *Agincourt*, and also the account of the experiments which were made with the model of the *Inflexible* in 1878 as to tipping when the end is riddled, will, I think, agree that the protection of the ends of the ship is a very important matter. I am in hopes that this material which Sir Nathaniel Barnaby has called attention to may come in useful for that, for it is certainly a very great advance on anything I have heard of before. The expense of woodite was formerly prohibitive.

Captain G. H. Noel, R.N. (Associate Member of Council): Being the third naval officer who has spoken in succession, I am afraid you will be tired of hearing what the Navy has got to say; but I won't be very long. In the few remarks I have to make I hope that Sir Nathaniel Barnaby and the gentlemen present will excuse my dwelling not so much on to-day's paper as on yesterday's. I would like to express my entire confidence in the exceptional ability of the Chief Constructor of the Navy, Mr. White, and to thank him for his admirable paper of yesterday. I believe that he came back to the Admiralty fully intending that what he did there he would do in concert with the naval authorities, and it was in consequence of his carrying out that intention that we get this new type of ship, which was so greatly approved of in the discussion yesterday. I shall make some few references presently to the *Admiral* class, for which I see by the diagram on the wall Sir Nathaniel Barnaby was more or less responsible. I think that Sir Nathaniel has made an error in departing from his views and opinions as expressed in that class of ship, to go to what he has shown us to-day. I cannot conceive that it is possible to build any smaller armoured vessel at a lower cost per ton than a larger vessel. If it was so, perhaps it would be as well to build a larger number of small ships. Again, this vessel of Sir N. Barnaby's cannot be considered a ship of the line; she is more of the nature of an armoured cruiser, than what we consider a battle-ship, and England *must* have ships of the line. I will make just a few remarks on certain points. First as to the disposition of the armament, I think the whole meeting yesterday was agreed that the disposition of the armament in the new barbette type was all that could be desired. The armament is very similar in disposition to that of the *Admiral* class, which has been so generally approved of in the Naval Service. It is a great advantage that in the new battle-ships the size of the gun has been limited to 67 tons; this is by many naval officers considered extreme—in fact, the general view is that the smaller nature of guns are more serviceable; but when we consider that these ships are to be of 14,000 tons displacement a principal armament of four 67-ton guns is not excessive, and they could not be better arranged than in pairs as is intended. The disposition of the minor battery is also exceedingly satisfactory. Another great advantage in these new ships is derived from the fact, that the total weight of armament is so much in excess of what we have had hitherto. It is all very well to insist that we must have protected ships, but it is equally necessary that ships should have great offensive power. What we want to do, as Lord Charles Beresford told us yesterday, is to be able to drive the enemy from his guns; if we can do this we need not fear him, and in order to do it our offensive power must not be curtailed. Next as to the question of speed. Here I differ from a great number of naval men

* "Any excess over what is necessary is most objectionable owing to the increased weight and size of target involved in it."

and others. I consider it is a very great misfortune that the Government of Italy should have constructed battle-ships of the speed of the *Italia*. If they had not done so, it would have been unnecessary for us to have followed suit (which is, of course, necessary under the present circumstances). But our reason for following in their steps is not the reason for which the Italian vessels were given such great speed. Italy is not the first Naval Power in the Mediterranean; her ships, therefore, in the event of war, would probably be required on occasions to make what is called a strategical movement to the rear, whereas with us whatever be the nation with which we may happen to be at war, I trust we shall meet our enemy at any rate on equal terms at sea. Of course, nobody can deny that it is a great advantage, that you should be able to bring the enemy into action, but the principal advantage of speed is to avoid action, and that I hope we shall not be required to do. What does speed mean? Speed requires a compromise, as we heard yesterday other things required a compromise. If you have this tremendous speed you have to put into your ship engines of immense power, which entails reducing other things; you cannot carry the spare gear that is necessary to replace machinery injured by accidents; you cannot carry the staff that is necessary to put the engines into thorough working order if seriously damaged; and, in fact, your ship is not self-sustaining. The older vessels with more moderate speed *were* more or less self-sustaining. Our very rapid cruisers will be often damaged in war time, and frequently in the hands of the dockyard authorities in consequence; this is a very serious consideration. Lastly, as to the question of armour. To my mind vessels of the *Trafalgar* class are too heavily armoured; Lord Armstrong yesterday stated what was no doubt the fact, that if you wish to have a ship that cannot be sunk, that is, so protected that she is invulnerable, you cannot make her a fighting body. We do not want to be all protection. We want to have some offensive power as well as being, to some extent, protected; on this question, speaking of the *Admiral* class, I stated in a paper read at this Institution in 1885, that with an addition of about 150 tons of 3 in. steel plating, sufficient to give the *Collingwood* a 6 ft. water-line belt at her unarmoured ends, I thought that she would be as capable and effective a vessel as any afloat at that time. I still adhere to that opinion, and the only thing I regret in the new type is that the water-line in the fore part (which is very much shorter than the unprotected forward part in the *Collingwood*) has not been supplied with a certain amount of armour protection. Mr. White yesterday explained how effective a 5 in. armoured side would be over an armoured deck. I wish that he had carried that 5 in. side in the new design over the armoured deck before the citadel. If the 8½ ft. belt at the water-line was carried to the bow, with, we will say 4 in. armour, it would be a very good way of using up 100 tons—(I do not think it would be more)—of the Admiralty Board margin. We heard a good deal about the Board margin, and I think that that would be a very good way of using up 100 tons of it; of course, it would necessitate the other weights being moved a little further aft, but I am sure that most naval officers agree with me that a certain amount of protection at the bow is most essential, for we want to keep the water out forward, and we want also to support the ram. I am afraid I cannot say more about the present paper. I only got it when I came into the room. I thank you for having listened with so much patience to what I have had to say.

Sir Edward Reed, K.C.B., M.P., F.R.S. (Vice-President): The gallant officer who has just spoken has held forth great temptations to me to wander back into the fields which we traversed yesterday, but I hope, without wishing to complain of that, that I shall not be lured into that path. There are about half a dozen sentences that I should be extremely pleased to say, but I do not think it would be fair to say them on the present paper, because we have other papers to follow. The day is short, and we must concentrate the discussion as much as we can. With regard to this paper, my Lord, my

remarks will be very brief indeed. I recognise in it the indication of the fact, which, indeed, was already intimated to us as long ago as the design of the *Inflexible*, that in the mind of the late Director of Naval Construction, however widely he and I may seem to diverge in some respects, there has been at work the same thought that has been at work in mine, namely, that the sea is a terrible thing to let into your ship. It is a very evil ally to give to the enemy, and the best thing that you can do is to keep it out of your ship if you possibly can. It is all very fine, it is no doubt very noble, splendid, gallant, brilliant, for naval officers to come and say, "We do not care about defence; give us plenty of guns to fight the enemy." But if you admit the sea, and let it send your ships to the bottom, there will be very little fighting after they get there; and consequently, in one form or another, we naval architects may be more sensitive to, and possibly, if naval officers will forgive me for saying so, more sensible of the dangers of the sea's invasion into the ship than they themselves recognise. It is a part of the new epoch, and gallant officers here will bear me witness when I say that the invasion of the sea into the ship was not regarded, or had not to be much regarded, in the old days of naval warfare. You could not get through the ship with the shot and shell to which you were then exposed.

Admiral Sir E. Ommanney, C.B. (Visitor): There were no shell.

Sir Edward Reed: Quite so. In the old days of the great wars there were no shell, and the shot could not get through, as a rule, the battle-ship's water-line. A battle-ship was a very heavy and solid affair, composed usually, in this country at any rate, of very solid and sound material, namely, Italian oak. However, Sir Nathaniel Barnaby's paper suggests a method of enormously reducing the cost of the ship by setting at nought, within certain considerable limits, the possibilities of the sea's invasion, and from that point of view I regard it as of the utmost importance. I do not suppose that Sir Nathaniel Barnaby expects—if he does, he puts a much less value than I think he should upon the weight which the Government can always bring to bear upon any and every proposal which they may choose to bring forward—I do not suppose he expects at the present moment, and at the present time, to influence Admiralty construction, and possibly he may not expect even in the long run to substitute the ships of moderate, very moderate, size which he has put forward for the line-of-battle ships of this country. I am bound to say I agree with those who desire, and are prepared to go to the necessary expenditure for big ships. I believe that big ships have many advantages which it is impossible to give to little ones, and which it is peculiarly desirable to give to the ship of the British line-of-battle. One of them has been adverted to, I think, in the suggestive though very short speech of Captain Long, namely, that in the matter of steaming, the long and big ship can sustain her speed in a manner which is quite impossible to the smaller vessel, and that is a great consideration. I believe, myself, in large ships, and I believe that the country is perfectly able to build them, and pay for them, and does very good work when it produces them. The paper turns my mind rather to the other ships. We have talked a great deal about the eight or ten ships that are going to be built of the big class, but we have said nothing at all at these meetings—there has been no opportunity of saying anything—about the sixty other ships, and I should very much like to know—I hope Mr. White will give us the benefit of his observations directly, and if it lay within the scope of the official permission, under which he has naturally to work—I hope he will tell us, whether the sixty ships, unarmoured ships, or any of them, are going to participate in any of those unrevealed advantages which are to be given in the new design in the shape of protection to the minor armaments of those ships, advantages of which you may remember he stated yesterday he was not at liberty to speak. I shall be glad if he will tell us whether the unarmoured ships are going to have any of these advantages. It would interest me extremely to know that. But anyhow, my Lord, I feel this, that in bringing forward a material of this character, which it is possible to improve, but which as it stands

has the approbation of Sir Nathaniel Barnaby, for the specific purpose for which he has proposed it. he seems to me to have opened up a field of great advantage to which the Navy, in the sense of filling in those spaces within the ship which, where the ship is wounded, would otherwise become filled with the sea, and from which spaces the remaining parts of the ship would become filled with the sea if it is there admitted. By filling them up with a light material of this description he cuts off the sea's invasion for many purposes, in several parts of many ships, as effectually as if you plated the vessel in that part with armour a yard thick; and it is from that point of view that I attach immense value to the suggestion which this paper involves. I also think there is a very large amount of ability displayed in the ingenious manner in which Sir Nathaniel Barnaby has enabled this ship to strike out in all directions from a central battery without interfering with the efficient performance, so far as I can see, of the steaming arrangements. I will only add, my Lord, that I am extremely pleased to get back once more into some common concerted action with my esteemed friend and relative in furthering what we have both at heart, and what I believe it will be generally admitted that we both desire to further, namely, the strength and the security of the Naval Service.

Mr. E. H. Carbutt (Visitor): As I have spent some of my early life on the River Tyne, where Lord Ravensworth is well known in connection with the shipbuilding industry, and as I have carefully followed what the Government has been doing, I should not have liked this discussion to end without saying a few words. I feel some diffidence in doing so because my experience of shipbuilding is perhaps not up to date, and gentlemen here may criticise what I have got to say. The Government have taken a new departure in submitting the designs for their war-ships to the country, and I think it is a very good departure. I may say that in the difficulties I had with the Government on the gun question, my difficulty always was to get information, and on many occasions I got information as to what the English Government was doing through foreign Governments. I found that the foreign Governments could always obtain information of what was going on, when we in England could never find out anything. I am glad to find that there are so many of the foreign engineers and foreign shipbuilders here to-day to listen to this discussion, though, depend upon it, if they had not been here they would still have had information of what we are going to do. I think that by the Government laying the matter before the whole nation, and the whole world, we have shown the world that whatever happens we intend to protect our commerce. We are an island depending upon foreign sources for our food supply, and the Government have shown that they are not afraid of spending money. What we say to them is, that whatever number of ships they are going to build, we intend to maintain our superiority in regard to numbers and fighting-power of ships. Well, then, with reference to the discussion which has taken place between Sir Edward Reed and Mr. White, I do not intend to enter into that, but I believe we may thank Sir Edward Reed, and the attack that he made, for having induced the Government to lay these plans before the country, and by that means he has done some good. As to the question of Sir Edward Reed's attack I shall not enter into it, because, as Lord Armstrong, who is one of our greatest gunnery authorities in this country, said yesterday, on so short an experience of what is going to be built, we cannot offer an opinion so positively as would seem necessary, and therefore it is better for us to consider these designs, and if necessary lay our opinions before the proper authorities in a proper way. Still, my Lord, I think Sir Nathaniel Barnaby has done very good service by bringing his life-belt before us; because, as I look upon it, it is like throwing a sinking man a life-belt to keep himself afloat. My impression is, my Lord, that in addition to the attack now made by guns, in any future war the ram will play an important part, and upon this point I may refer to an accident that took place two years

ago in Holland. One of their battle-ships coming out of the dock was met by a small steam-tug. The small steam-tug drove right into the battle-ship. Where the armour-plating came it drove in the whole of the front of the steam-tug, but the bows of the steam-tug went into the bows of the armour-clad under the armour plating, and down went the armour-clad. I think if a small steam-tug could sink an armour-clad, going at such a slow rate of speed as they would be then, because they would have slowed their engines, we have a good deal to learn in the way of ramming, and in future wars I think many of our ships may be sunk by ramming. Therefore when we are asked by some of our friends to armour our ships so as to prevent ramming, and to prevent our ships being blown up by torpedoes, it means that we shall have to carry very much more armour if we want to make these ships unsinkable. But, as we were told yesterday, the whole thing is a compromise, and the means of attack must be kept up as well as the means of defence. I think everybody will be satisfied that Mr. White has treated this subject in the best possible manner. Mr. White has got the minimum of what he should not do, and the maximum of what he should do, from the men who fight the ships, and he has carried out the design which he has now submitted. I believe everyone who listened to the paper yesterday, that Mr. White read, will be satisfied he has thoroughly considered every question that has come before him ; and that if these ships are built, which I believe they will be, they will show good results for the money spent, and the nation will be satisfied. I have one suggestion to make to Mr. White. I do not know whether it is a practical suggestion, but he said yesterday that the great thing was, not to be able to run your ships continuously at a quick speed, but at a short notice to be able to put on the quickest speed possible. I know that Mr. White's attention has been drawn to the question of liquid fuel, because I have been to him several times about it. The price of oil has now come down so that it is only something like fourpence a gallon, and what I would suggest to Mr. White is that these vessels should carry a small proportion of liquid fuel which in case of emergency could be turned on under the flues with forced blast and thereby increase their steam-producing power, and obtain a greater speed rapidly when required.

The President : Gentlemen, I am compelled unwillingly to make an appeal to future speakers—that is, to stick to the matter under discussion. My duty here is to try, not to enforce, but to remind you of our rules. Our rules, which are very good and salutary, direct that people should confine themselves to the subject under discussion, and if we once get back into a field of discussion that has been disposed of, and which is practically endless, it will be very unfair to those who come here to speak upon another subject. Now I make that appeal to you, and I hope it will be ttended to.

Admiral H. Boys (Visitor) : My Lord and gentlemen, I certainly will be guided by your advice, and stick to the text which is before us, the subject of which is the protection of stability and buoyancy in ships. I presume to ask permission to say these few words, because I have been associated with Sir Nathaniel Barnaby to a certain extent in this design, and as the subject is buoyancy I will not touch upon the method of the armament, but simply to observe that this is an entirely new system of placing the guns in a ship, by which a perfect all-round fire is obtained without any obstruction whatever, and I think the facilities with which these guns can be worked, the whole power of the armament being in the hands of the commanding officer himself, the crews merely having to load the guns, are advantages which have never before been produced. As to the ship proposed by Sir Nathaniel Barnaby—I do not look upon it, and I have not looked upon it, as a battle-ship—I look upon four or five of them as equivalent to a battle-ship, and when unity of action can be obtained by putting them in the position to attack one large ship, of the class proposed by the

Admiralty, and which I believe is perfectly necessary for England, still, if we can get four or five of these small ships round one large ship in the open sea, I think the advantage will be in favour of the smaller vessels. The estimated cost of one of the new Admiralty ships, probably as she floats, is not much under a million of money. The object of the enemy is probably to destroy that million of money by something representing a million of their own money. The conditions of naval warfare are most uncertain: for instance, if the battle-ship could be caught inside the Isle of Wight in perfectly smooth water, I believe that half a million of money, represented in so many torpedo boats, would annihilate her—either send her up or down; but if the battle-ship should happen to be in the open sea, say the Bay of Biscay, in moderate weather, she might as well be attacked by butterflies as by torpedo boats. I think there must be an intermediate type of vessel between torpedo boats and ships of 14,000 tons, capable of engaging the latter with good prospect of success, and I think Sir Nathaniel Barnaby has hit it as nearly as possible in the ship which he has described of about 3,200 tons; the equivalent in value being about four or five of the smaller ships to one large one, and if they (the four or five) could meet the one ship on the ocean, I believe the chances of battle would be in favour of numbers, as against size. There is one point which Sir Nathaniel Barnaby has touched upon, and which has been touched on by the last speaker, that is, the ram view of the case. I think it is perfectly clear that the 3,200 tons as a ram would be an equally efficient weapon as 14,000 tons as a ram, and if one of these small vessels were to sacrifice herself by allowing herself to be rammed, the larger vessel would be destroyed, as she (the ramming ship) would necessarily lose her way and be stopped, and then she would be at the mercy of the other three or four, as the case might be. I think, also, my Lord, that the question of the vulnerability of the water-line has been too much dwelt upon, in fact, I may say it has been exaggerated by many—naval officers and others. Now I will give my experience—I do not want to speak of myself or what I have done or seen, but I think the only use of us old Naval officers is to give our experience, for the benefit of those who come after us. When I was a young gunnery officer I was in a ship that captured a slaver. I thought that was an extremely good opportunity to try horizontal shell fire, which had just been introduced. She had to be destroyed, and I asked to be allowed to have the opportunity, which our captain permitted me to take, to destroy that ship by shell fire, as target practice. This slaver was an ordinary built slaver, and she was anchored within 200 yards of us. There was a moderate sea, and she was rolling between 5 and 10 degrees. I thought it would be a very simple thing to put one or two shells into her and sink her, but actually we could not get a shot in between wind and water—in fact, with the slight sea there was, the hits were either ricochets or above the water-line. We struck her frequently and burst shell in her, but could not strike her so that the water would come in in any amount, so as to sink the vessel. Occasionally she lurched over and took in a little water, but we could not sink her, and ultimately had to go aboard with a bag of powder—which was exploded by Bickford's fuse, because there were no electric fuses in those days—and blow her side out. With regard to this substance which Sir Nathaniel Barnaby has shown us, it is apparently suitable for the purpose for which it is intended, to support the buoyancy of the ship at the water-line. The Naval Construction Company are not bound to this woodite; probably something of the same description, or better, may be invented. I quite agree in the principle that some substance of the sort will give protection to the buoyancy of a ship. Woodite is found to be uninflammable so far as shell fire is concerned. We have fired at a target constructed of it with a six-pounder shell, burst the shell inside it, and nothing has been ignited. As a private company, however, we cannot go into expensive experiments beyond that. I have only now to say that I think if we can get the engineering science of naval architects to join hand in hand with the experience of naval officers it will be greatly to the benefit of the country, but they must both work together, and not attempt to act separately.

Captain Orde Brown, R.A. (Visitor): My Lord and gentlemen, I want to raise a question with reference to armour—namely, whether we are not now sufficiently within measurable distance of getting high explosives into the interior of ships to make it desirable to consider whether we ought not to sacrifice something in the tenacity of the armour so as to secure keeping the shells out at any price. It is to be done, as we know, in extreme cases by chilled iron which splits it all to pieces, but allows nothing to pass through it, but short of such extreme hardness, there are many degrees in which we might increase our powers of resisting perforation. Would it not be worth while to try how far we should have to go, and how far we must sacrifice the plates' power of holding together, to make certain that there is no chance of perforation through the thinner class of armour I am speaking of 10 inches, and the thin armour employed on cruisers—and of getting high explosives into the interior. Plates of limited sizes might be tried such as could be put on and off with the least possible trouble. The principle was tried in another kind of way in the *Polyphemus*. There is another question which is especially suitable for the consideration of naval architects, which is this: Might not this sort of experiment be made in miniature? I think there has been a very great mistake in working everything out on a large scale. The actual laws we have established for perforation depended on miniature experiments made by Sir William Fairbairn. Sir Joseph Whitworth has also made miniature experiments. It saves money. We are now told here that that does not much matter, but I do not know whether they say that at the Admiralty; however, what is more important is that it saves an enormous quantity of time. With a few pounds we could carry out sufficient experiments to indicate the direction in which to proceed, and to find what experiments you could make with advantage on a large scale, and thus guided, one or two experiments on a large scale would tell us as much as years and years would do otherwise. There is one question more. I do not know whether reference to published information on results of Government experiments comes within the scope of the paper. This, at all events, concerns naval architects, and those who build ships, very nearly. If it is desirable that we should make armour and ships at private firms, it seems to me to be desirable that we should have as much information as is allowable, with regard to what goes on. The Admiralty and War Office undoubtedly are the only persons to decide what is to be treated as confidential, but the question is not fairly put under present circumstances. Speaking from my own experience, I may say I used at one time to be a perfectly irresponsible individual writing on these questions, and everything I learnt I wrote. I am now in the responsible position of Government Lecturer, and I am allowed to see everything. I now, of course, raise the question before writing or using information publicly. I say, Can I write on this? and I am told always, No. At present, however, responsible officers see the question only from the official aspect it presents. Trouble may arise from allowing publicity, none can arise from preserving silence. There is, however, another side of the question, and a side of some national and commercial importance. Should not the Intelligence, or some other Department, be deputed to consider the matter in both aspects? If there is any objection to these results being known to foreign countries, it may be stopped at once, but if there is no objection to that course being pursued, then let it be borne clearly in mind that it would be of very great advantage that the results should be known for reasons which are never put before our responsible officers. Private firms exist which, in time of war, would form extra arsenals; such firms cannot conduct a trade in war material to full advantage, unless results obtained on trial are known. We cannot expect to have arsenals kept up by foreign money (for this is what it comes to), unless foreigners know what we are able to do. On this account, it is very desirable to awaken public opinion, so that the question should be put before the proper authorities and a decision come to. If there is no objection to any results being known, let it be clearly understood that it is most important that they should be known and published in a correct and reliable way.

Let the authorities decide each case on its own merits, but decide with both sides of the question presented to them.

Mr. S. W. Barnaby (Member): My Lord and gentlemen, I will be very short in what I have to say. It is really a suggestion as to a possible use to which, it seems to me, the new water-excluding material brought before us by Sir N. Barnaby might be put. Those who have been present at the discussions of the last two days cannot fail to have been impressed with the fact that, certainly among the naval officers who attend these meetings, there exists dissatisfaction as to the *Admiral* class of vessels. It may be useful to see what are the particular features in the ships to which exception is taken, and whether it would not be possible to make certain simple modifications which would remove the grounds for complaint. It is said that the water-line is insufficiently protected, and that the men in the batteries are unduly exposed. I believe I am right in saying that the spaces in the unarmoured ends above the armoured deck are already filled up to the extent of five-eighths of their capacity with coal and stores. Would it not be possible to fill this space up solidly with the new packing material from the armoured deck to above the water-line, and so exclude water altogether? We are told that the fuel supply of these vessels is unusually large. Might not some of this redundant fuel be given up for the sake of obtaining this result? With regard to the exposed batteries, looking at the diagrams of Mr. White's new ship, you will see that the batteries containing the auxiliary armament have not the slightest shading over them representing armour, but there is some new device for protecting those guns, the nature of which is undivulged. Would it not be possible to apply the same device for the protection of the auxiliary armament in the *Admiral* class?

Mr. W. H. White, F.R.S. (Vice-President): My Lord and gentlemen, I will take first, if I may, the remarks which Mr. Barnaby has just made and his suggestions, as he personally appealed to me, and I would like to say at once, in relation to the consideration and trial of packing materials in whatever form presented, that the Admiralty has not at any time been behindhand. I am not aware of any material, either woodite in any of its forms or any other material, which has been proposed to the Admiralty which has not been experimented with and its merits duly considered. It may be assured, therefore, that in the preparation of recent designs this possibility has not been overlooked. There have been repeated references in the course of the discussion to the other point which Mr. Barnaby made, namely, as to the want of disclosure of what Sir Edward Reed was good enough to call the "unrevealed advantages" by which we hope to provide for the protection of the guns and guns' crews in the new designs. The phrase reminded me—if Sir Edward Reed will forgive me for alluding to it—of another phrase, which, about twenty years ago, was very familiar to Mr. John and myself, who were then youngsters at the Admiralty working under Sir Edward Reed. We then had a phrase which referred to the "great undivulged" arrangement of armour which Sir Edward Reed had under consideration. We will call this present arrangement the "great undivulged," if Sir Edward Reed prefers it. As a matter of fact, what I have said in the paper is all I can say, viz., that a liberal allowance of weight has been made for this protection. I cannot go further. We have allowed weight; we have plans for protection which we believe to be the best, in view of the *Resistance* experiments, but we do not desire that they should be public property at present. I want to add one statement: in all the large vessels in the new programme these "unrevealed advantages" have been provided for, whether the vessels are called cruisers or not. Reference was made by Mr. Barnaby to what might be done in the *Admiral* class by using packing materials. I do not think, if I may be permitted to say so, that this is quite the place to discuss that point; and I do not take it that Mr. Barnaby, in making that suggestion, speaks for his father. If Sir Nathaniel Barnaby had any proposal of that kind to make, he would make it, no doubt, in a form which would admit of its official

consideration; and which would deal completely with all the problems that must be involved in adding more weight to ships which, by means of additions to their armament and equipment, have already been put deeper in the water than they were originally designed to be. Now, sir, if I may be permitted, and I hope Sir Nathaniel Barnaby will excuse my doing so, I will endeavour to answer certain questions. The discussion has inevitably taken the form of asking for information on many points relating to the new battle-ships, and it may be of interest to the Institution if I give this information as far as possible. In doing so I think my remarks will have some bearing also on the paper which Sir Nathaniel Barnaby has read. Sir John Hay and Captain Noel both touched upon the possible advantages to be gained by the extension of the water-line belt to the extremities. Captain Noel suggested that might be done with thinner armour than is fitted amidships. As a matter of fact, the idea was most carefully considered, and the weights which would be involved in constructing either a thick belt of armour or a belt of armour of moderate thickness, or of carrying the armour of moderate thickness high up on the bow, were all considered before a decision to do neither was arrived at in the new designs. Captain Long has spoken in relation to the freeboard of the new ships, and he has made a calculation, which is probably correct, to the effect that if the ship pitched four degrees, she would immerse 13 ft. 6 in. of her bow. That, no doubt, is roughly right. It is one-fourteenth of her half-length. But even when the bow is so immersed the new barbette ship has still five feet of height of side above water. Captain Long did not proceed to say that in all the existing ships of low freeboard or moderate freeboard, of which we have so many, the same moderate extent of pitching would put the upper deck completely under water and would pile up a great heap of water on that deck. Of course the question of freeboard is one which is intimately associated with the power of maintaining speed at sea, and it was considered from that point of view primarily. In the new ships the freeboard forward will be about 19 ft. as against 10 to 11 ft. in many existing ships.

Captain S. Long, R.N.: My Lord, might I say one word? I would draw attention to which you would rather have in front of you, water or unarmoured structure, in an action.

Mr. W. H. White: If I may proceed with what I am saying, I will deal with Captain Long's point afterwards. The question of freeboard was primarily considered in relation to the maintenance of speed at sea. We have had reports on the steaming of the *Admiral* class, which have upper decks as high as any of the turret ships, while their guns are placed much higher; and the conclusion drawn from these reports is that it is undesirable to repeat the moderate freeboard of the *Admiral* class in vessels which are intended to maintain high speed. Therefore, that is the governing condition. Having accepted the high bow, the question comes in, to which Captain Long very properly calls attention: How shall we deal with that high end under the circumstances of action? There, also, the new ships will possess some "unrevealed advantages," which have been worked out in great detail. We have minutely subdivided the space, and provided arrangements for checking any flow of water, going much beyond the corresponding arrangements in any ships yet built. Taking into account the very moderate capacity of the unoccupied space between the top of the protective deck and the normal water-line, as well as the very minute subdivision and the special precautions to which I have referred, there is good ground for the decision we have come to, not to protect the spaces by means of large areas of thin side armour. The entry of any serious quantity of water is, in fact, most improbable. Captain Long referred to the *Inflexible* experiments, and to "tipping." Now I have had before to speak of these experiments, and to explain some misapprehension respecting them. The *Inflexible* experiments as to tipping were in no sense representative of the condition of

the actual ship. The *Inflexible* model was drawn along at a speed which the ship could never have reached in the condition in which she was supposed to be. By sheer force of a stationary steam-engine, placed at the end of the experimental works, the *Inflexible* model, in a damaged condition, was made to tip and stand a good deal "on end." But this great change of trim occurred only when the model was moved along at a speed which could never have been approached by the engines of the ship, supposing her to be similarly damaged. In fact, the experiments were conducted as a scientific investigation of great interest and importance, but they did not represent actual conditions for the ship. Moreover, this "tipping" was shown to be greatly reduced, or almost destroyed by the interposition of transverse cofferdams, which prevented the flow of water along the deck. It was the *dynamic effect* of the flow of water, and not the statical alteration of trim due to the mere entry of water into the ship or model, which produced serious "tipping" in the sense in which that term was used by the Committee. Sir John Hay remarked that if the turret design is better than the barbette, why not have all turret ships? Or, if the barbette ship is better than the turret, why not have all barbette ships? As a matter of fact, the passage in my paper which, to save time yesterday, I omitted —that in which the barbette design is described—gives exactly the information which Sir John Hay asked for. It comes to this. The Admiralty had before them these facts: In the Royal Navy there are a great many turret ships of moderate freeboard. In foreign navies there are a great many ships armed on the barbette system, with their guns very high above water, and with high freeboard. The following passage in my paper exactly describes the Admiralty action: "The advantages and disadvantages of both systems having been reviewed, it was agreed, in view of the vessels existing in foreign navies, or now under construction, that the barbette arrangement was to be preferred in a battle-ship intended for general sea-going purposes. Sir Arthur Hood recommended that of the four ships to be laid down in 1889—90, in the dockyards, one should be on the turret system." The question has been raised by Sir John Hay as to whether Sir Arthur Hood concurs in the final decision as to these ships. As a matter of fact, Sir Arthur Hood is in full agreement on this point with the decision which has been come to. I am in no sense speaking for him, but that is the fact. There need be no question at all but that the decision which has been come to is one which is thoroughly approved by the very experienced and distinguished First Naval Lord of the Admiralty. Remarks have been made also about the behaviour of the Admiralty in relation to the publication of facts of public interest, such, for example, as the trials of armour plates. Perhaps I may be allowed, my Lord, just to refer to that point. The facts are these: trials of armour-plates have been recently in progress, and have been made primarily to ascertain the present condition of the manufacture of steel armour in this country, and the possibilities of extending the area of supply. It is perfectly obvious that publication under these circumstances would not be just to the makers, who are sending in experimental plates with a clear understanding that in this stage of proceedings only they themselves and the Admiralty shall have reports.

Sir Edward Reed: Might I just ask Mr. White if he would say a word as to whether he knows of any objection to our having the experiment with models as to the conditions on which the speed of these ships rests. It seems to be a purely scientific one.

Mr. W. H. White: I should like not to commit myself at all upon that point, because it really involves an important question of policy. But I presume Sir Edward Reed will be prepared to accept my word that the facts which are given in the paper are correctly stated, and these are the only facts which are at all germane to the discussion which is now proceeding. I think those are all the points in reference to the new designs which have been raised to-day. I should like now, if I may be allowed

to do so, to say a few words on the subject of Sir Nathaniel Barnaby's paper. There was a phrase which appeared in a pamphlet of great ability, published in France at a time when the torpedo boat craze was prevalent, which has always remained in my mind. It was written by M. Weyl. He said that in his experiences as a seaman he had always found "the sea kindest to the largest ships." I think that doctrine, applied to Sir N. Barnaby's proposals, not merely raises the question of maintenance of speed, but also touches the very important question of steadiness of gun platform. Although that point has not been mentioned in the paper, I will content myself with mentioning it. It is not conceivable that a ship of the size proposed by Sir N. Barnaby, however armed, can compare in steadiness as a gun platform in a seaway with the large ships proposed to be built. Sir Nathaniel Barnaby, I am sure, will agree with that. The question of maintenance of speed in rough water leads me to notice an unintentional mistake made by Sir Nathaniel Barnaby. The new battle-ships are to be capable of steaming at 16 knots an hour continuously; whereas the design put forward by Sir N. Barnaby probably provides for a continuous rate of steaming of 15 knots only. The actual maximum speed proposed for the new battle-ships is 17½ knots, not 17 knots, as in the small vessels described in the paper. A half-knot is not much, it will be said, but it is something to obtain at that speed. Moreover, in comparing the *Admirals* with the new battle-ships, Sir Nathaniel Barnaby speaks of the *Admirals* as being equal in speed to the new ships, but he does the new ships an injustice. Furthermore, he describes the new ships as being similar to the *Admirals* in armament. Of course he wrote his paper not knowing the facts as to relative weights and powers of the auxiliary armaments in the new ships. The Parliamentary papers did not give the facts as to relative weights which I gave yesterday. But as a matter of fact, as I pointed out yesterday, the new ships will have in their auxiliary armament a weight equal to that of twenty 6-in. guns, with the provision of ammunition which was in vogue when Sir Nathaniel Barnaby held office; and these are to be quick-firing guns. So that the new ships not merely carry ten 6-in. guns instead of six of the same calibre in the *Admirals*, but have the much more rapid fire which is possible with the quick-firing arrangement, and the much larger supply of ammunition. I think with the facts I gave yesterday before him, Sir Nathaniel Barnaby will scarcely be prepared to maintain that the *Admiral* class, as they have been built, are equal in armament to the ships now proposed. In the design described by Sir N. Barnaby, great importance is attached to the advantage supposed to be gained by an all-round fire from a single and central protected position. Like all advantages, however, in ship construction and armament, certain inevitable disadvantages are involved. For example, practically nothing is mounted in the proposed vessel in the nature of a modern quick-firing gun. There is practically no auxiliary armament, the only addition to the two guns shown being a few quick-firers mounted under the deck. It does seem to me a serious drawback to have only guns like the two 9·2-inch guns shown in Sir N. Barnaby's design, which guns, while powerful when they are fired, can only be fired much more slowly than the other guns. Of course it would be possible to exchange those 9·2-inch guns for quick-firing guns in greater number, but then you will deprive the vessel of a feature to which Sir Nathaniel Barnaby properly attaches great importance, namely, the possession of guns capable of perforating the armour of a great many foreign ships. Nor is that all. I am speaking now of the disadvantages coming from the adoption of the single position and the all-round fire. Protected and mounted as these guns are, I do not hesitate to say that with projectiles of very moderate calibre the whole of that battery might be put out of action by a single blow out of the many that can be delivered in a minute by a quick-firing gun. These are but slight disadvantages, of course; Sir N. Barnaby is correct in claiming that there are advantages in having the risks distributed over several vessels. But if naval tacticians say—as has been said in this room both to-day and yesterday—that a group of ships of moderate size could not safely be fought against a smaller number of large ships of greater

individual power, it appears to me that the naval architect is scarcely the person to question that decision.

Admiral Sir Erasmus Ommanney, C.B. (Visitor): What is the difference in coal-carrying power between Sir Nathaniel Barnaby's ships and your own?

Mr. W. H. White: Sir Nathaniel Barnaby can answer that better than I can.

Sir Nathaniel Barnaby, K.C.B. (Vice-President): I will not take up your time more than a few moments. The question of speed has been very well dealt with by several speakers, but I should like to say I find that there would be no difficulty whatever—I have had statements put into my hands which show that there would be none—in doubling the engine power in those ships with the weight which has been taken for the machinery in them. I quite understand and accept the difficulty in keeping up the speed in small ships as compared with what you can do in larger ones. Mr. White said just now that the question of the use of a number of ships as against one was a question for naval tacticians, and not for the naval architect.

Admiral of the Fleet Sir Geoffrey Hornby, G.C.B. (Visitor): What is the length of your ship?

Sir Nathaniel Barnaby: 260 ft. I will refer you, as to Mr. White's point, if you will be so good as to let me, to Admiral Boys, who is a naval tactician. He has said what I would not venture to say myself, and I will leave it as he has put it. The proposal made by my son, which was made without any concert with me, is an obvious proposal. It has never been out of my mind from the time when these ships with unarmoured ends were first thought of, that they can always be treated as if they were absolutely solid, and that you could make them solid if you wished it. That has always been in my mind, and I have always failed to see why Sir Edward Reed did not himself recognise that. I won't say he has not recognised it. Perhaps he has; but, at all events, I am most grateful to him for what he has said this morning, because, perhaps, he and I may see our way in the future to better agreement than we have in the past. I shall be most thankful if that is so. But as to the question of treating the existing ships, I should like to say just this: Mr. White is right in saying that if I have any proposal to make I should make it directly to the Admiralty. Well, I think I should not make any proposal. My experience in that matter is that the fewer proposals you make to the Admiralty, the better for you (Laughter.) But I may say, without breach of confidence, that Mr. White and I have been in agreement as to this: that the engine performances of the ships of the *Admiral* class have so surpassed what any of us expected, that we considered they were carrying too much fuel; and he and I—I hope I am not doing wrong in saying that—quite concurred in recommending that the amount should be reduced. Well, now, I do not press that, if the Admiralty say, "No; we would rather have that additional fuel in, which you say we do not want, than have these ends filled in solidly." Very well; go on. Only do not turn round on us and tell us that not having the ends filled in solidly is such a desperate thing for the ships. If you say you are not going to give up the coal which we say you do not want; if you are not going to reduce your ammunition; if you are not going to reduce your stores, which are redundant in a great many places, for the purpose of getting rid of a feature which Naval officers do not like (which you can do by filling in the ends solidly), then do be quiet, and leave me alone. Now, sir, just one word more as to the Navy having been taken into the confidence of the Admiralty. There sits my old chief (Admiral Sir Houston Stewart), one of the best chiefs any man could ever have. He knows quite well that there never was a step taken without his complete concurrence. One of the things he used to say was this:

"I am not going to be *un Roi fainéant*," and he was not. Not only was he there to do what he wished, but he had by his side some of the most able naval officers I ever met. I will only instance Admiral Sir Cooper Key. I say that those naval officers who come here to try to damn the ships that Sir Cooper Key has given his approval to, show an amount of presumption which I am surprised at. But I will just say one word more, which is this: I believe I am right in my recollection that the *Collingwood*, which was our first barbette ship, was designed upon consideration, not of first-class ships at all, but of second-class ships, and that she grew out of a consideration of a class of French ships called the *Caïman* class. I should like to say, too, that with the exception of the barbette armament, which Admiral Sir Arthur Hood did not like, I believe—I am sorry if I am misstating, because I am trusting to my memory now—I believe he was a member of the Board who approved of the *Collingwood* design. At any rate, there were most able officers who were consulted on every point, and it is most unfair to me, and most unfair to them all, to speak as some naval officers have spoken here, as if for the first time in the recent history of the British Navy naval officers were being consulted as to what sort of ships should be built.

Admiral Sir W. Houston Stewart, G.C.B. (Visitor): I only rise to confirm what Sir Nathaniel Barnaby said. During the ten years that I was at the Admiralty, the Admiralty of the day, one administration after another, used the utmost endeavours to obtain the views, opinions, and criticisms of naval officers in regard to the designs proposed, and I confirm what I said yesterday when that noble lord, gallant naval officer, popular orator, and efficient member of Parliament was speaking, that during the time that I was Comptroller of the Navy, no design went forth from the Admiralty that was not stamped with the Board's seal in the presence of the Board of Admiralty, and signed by the responsible naval officers of the day. Sir Edward Reed paid me the compliment in a letter in *The Times* the other day to say that he believed I was primarily responsible for the *Admiral* class. If it is so, I may accept that responsibility with pride, because I was associated with some of our most distinguished and most efficient naval officers who formed the Board of Admiralty at the time that class of ships was designed. I hold in my hand here some papers; on leaving the Admiralty one retains sometimes a record of what has taken place there. Here are the papers in which the designs of the *Collingwood* class and the *Admiral* class were submitted to the Board, which show that the design of the *Collingwood* as a type of the *Admiral* class was not the ship that Sir Nathaniel Barnaby first submitted to the Board of Admiralty. There are four designs of ships here which he laid before the naval officers, and they were under their consideration many weeks—I may say months. One design was an improved and very powerful vessel of the *Italia* and *Lepanto* class: that class of ship very much improved. The next was an improved *Inflexible;* the next was a very much improved *Dreadnought*. The next was of the class of the *Inflexible*, I believe, as recommended by Sir Edward Reed, in which the ship was to preserve her stability, and to go into action with a certain quantity of water in the ends. But, however, those were the designs that were submitted by the Director of Naval Construction, and it was by the desire, and under directions received from the first Sea Lord of the Admiralty, that the reductions were carried out by Sir Nathaniel Barnaby, which resulted in the *Admiral* class. This class was expressly stated by the constructors to be second-class battle-ships, the tonnage being below 10,000, a reduction which in their opinion precluded the production of a design which could compete with the first-class battleships designed and being designed in France and Italy.

The President: Gentlemen, I hardly need ask you, for I am sure you will agree at once to return your thanks to Sir Nathaniel Barnaby for his paper, upon which so highly interesting and instructive a discussion has ensued. I could have wished, to speak my own opinion, and I rather

think the opinion of some others, that the discussion had been a little more confined to the paper itself, and had not dealt so largely with the discussion of yesterday. I should have wished that, but at the same time we must remember that public attention is centred at the present moment largely upon the new designs, and therefore it is quite intelligible, and I think quite pardonable, that people here should have taken the interest they have in the new designs. There is only one more remark I wish to make, but I think it is not altogether without its importance. One of the many able speakers who have addressed us to-day talked about the new departure of the Admiralty in sanctioning a discussion in this hall or anywhere else upon the new designs. I entirely concur that the Admiralty have taken a wise course in that respect, but I think I am only doing my public duty—because I am a member of Parliament now as much as I was when I was in the Lower House—when I think it right to guard the public against being led away with the idea that this is a precedent that ought always to be followed. It is absolutely necessary that what is to be included in the phrase the "great undivulged," should be left within the Admiralty's own discretion. There are always important matters within the heart of the Admiralty which they do not wish to divulge, and I should venture to deprecate in the strongest way that the public should claim, against the discretion of the Admiralty, to have plans or designs divulged at their own will. I only wish to put in that word of caution, so that the public should not be led away with the idea that because it has been done once therefore it is always to be done.

Sir Edward Reed: Would your Lordship allow me to say that I believe it is quite a mistake to suppose that this is the first time that has been done. I think in the case of the very earliest designs I ever prepared, which were built from by the Admiralty, they were attacked in public, as these have been attacked, by some inconsiderate people, and I was authorised to come down and read a paper on the ships, which I did, with very good results.

The President: I am delighted to hear my friend talk about the "inconsiderate people," because there is no doubt whatever that the origin of and the reason why this most interesting discussion was sanctioned by the Admiralty was my friend's rather severe criticism upon the new designs.

THE PROTECTION OF MERCHANT STEAMERS IN TIME OF WAR.

By Captain C. Penrose FitzGerald, R.N., Associate.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 11th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

In view of numerous propositions for the protection of our mercantile marine in case of war with a maritime Power, and in view also of the fact that at present we do not possess a sufficient number of war cruisers to afford anything approaching to adequate protection to our merchant ships, we are face to face with the alternative of having our enormous trade destroyed, and the British merchant flag swept off the sea, with whatever trade remains transferred to neutral bottoms; or else shipowners must contemplate taking some practical and timely steps whereby they may render their ships to a large extent self-protecting against everything but the most powerfully armed war cruisers of the enemy.

I propose to point out how I think this protection may be secured at very moderate cost, and by the most simple means.

The forty or fifty first-class steamers which are already on the Admiralty list, and are built to certain specifications, strengthened so as to carry a considerable number of guns, &c., do not come under my notice. I will pass them by, merely observing that, although I think the precaution of preparing to arm them an exceedingly wise one, yet I do not believe their proper function in war time will be to act as regular men-of-war cruisers, for which they are ill-suited, but I rather believe that this enormous amount of first-class steam tonnage will be required to keep up the supply of food and raw material for manufactures, without which we cannot exist, and their armament will no doubt enable them to defy capture by everything except first-class cruisers and ironclads.

My proposition is a much more modest one, and may be applied to second and third-class steamers.

A considerable number of years' experience at sea, and some knowledge of the behaviour of ships, has led me to the conclusion that there are some strong practical

reasons why a steamer that is being chased has some very decided fighting advantages over the steamer which is chasing her, and so long as she maintains the "stern on" position, which she can always do as long as her steering gear remains in working order, no matter what superiority of speed the chaser may have, it seems to me that she can neutralise to a very large extent the fighting advantages which a man-of-war possesses over a merchant ship.

The example of the *Alabama* has long been held to be irrelevant to our present conditions; for I believe she captured only one steamer, all the rest being sailing ships, and we must contemplate the laying up of all our sailing ships in war time; but if our large merchant steamers fall an easy prey to every insignificant war cruiser of an enemy, it will be their own fault, for there is no occasion for it if ordinary precautions are taken in time.

My propositions are simple and inexpensive, and can be carried out in all ocean-going steamers.

First, a thwart-ship coal bunker abaft the engines. It need not go right across the ship. Say 15 or 20 ft. wide, 10 ft. thick; the top of it two feet above the top of the cylinders, and the bottom of it on a level with the screw shaft. Such a bulwark would form a very effective protection for the engines against the bow chasers of most cruisers.

Second, mountings and fittings for two light guns (say 4-in.) right aft, one on each quarter.

I do not propose any protection for steering gear; that would be too complicated, and the steering gear must take its chance; but it does not seem to me that loss of steering gear need stop the ship.

The tactics would be very simple. Keep your stern on to your enemy, and run away; head to wind if possible.

Let us now consider the size and vulnerability of the two targets which each ship offers to the other, and the chances there are of hitting them. We should not take extreme cases, of very small merchant steamers and very large and powerful cruisers; nor *vice versâ;* but rather the mediums on both sides—say, Beam of merchant ship, 45 ft.; height of merchant ship without superstructures, 20 ft. Beam of cruiser, 40 ft.; height of cruiser, without superstructures, 12 ft. The merchant ship's wheel-house and steering gear must be considered separately; they, of course, are greatly exposed, and highly vulnerable, but I may fairly assume that the merchant ship will be considerably longer than the cruiser; that she will have a longer floor, and will consequently pitch less; and although this will make no very great difference in the size of the *actual* targets to

be fired at, it will be much in favour of the merchant ship, as affecting steadiness of gun platform, and of the area of *vital* targets exposed.

The members of this Institution may perhaps remember that I hold somewhat strong views with regard to ships' water lines; or to express it more correctly, with regard to that area or belt on ships' sides, which is alternately covered and uncovered by water when a ship is at sea, even in very smooth weather; and which becomes a very extensive area when there is any considerable wind and sea.

When ships had thick wooden sides, shot holes in this area were not necessarily vital to the life of the ship unless there were a great many of them: and it still seems to be the opinion of many of the most enlightened naval architects, both in this country and in Italy, that the same holds good in ships with thin iron sides. I hold different views, and I believe that no matter how many compartments a ship may be divided into, two or three shot holes in the area mentioned will either disable, capsize, or sink any iron or steel built ship.

Now, in drawing a rough sketch of what I consider will be the vital parts exposed in the chasing cruiser and the chased merchant ship, it must be remembered that the primary object of each ship is to stop the other. If the merchant ship can stop the cruiser, she will certainly escape: and if the cruiser can stop the merchant ship, she will certainly capture her.

We will assume that the cruiser has the advantage of a couple of knots in sea speed (a somewhat bold assumption for most of our own cruisers), and the merchant ship is able to steam to windward, not necessarily exactly head to wind, and yet keep the cruiser directly astern of her. It seems to me that in the accompanying sketch (Figs. 1 and 2) the shaded parts will give a fair idea of the respective vital areas exposed in the two ships.

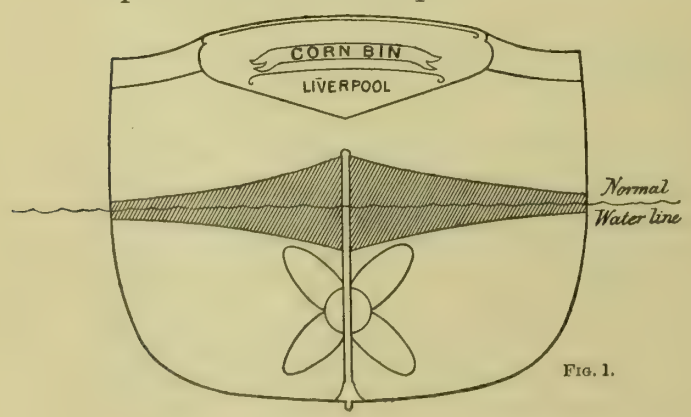


Fig. 1.

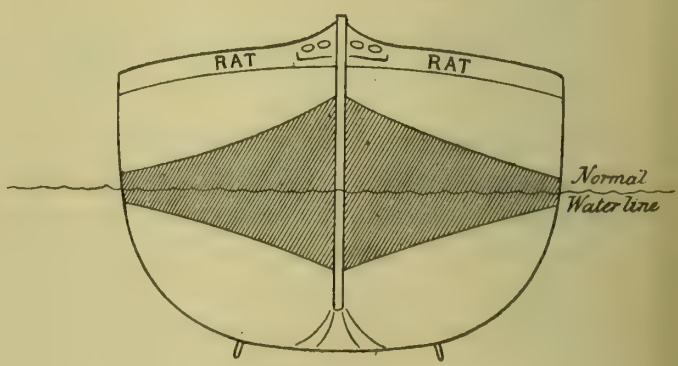


Fig. 2.

I have drawn the area of the cruiser's vital target larger than the merchant ship's, for the following reasons:—

First, the cruiser is fairly assumed to be shorter, and necessarily pitches more.

Second, the disturbance of water at the bows of all ships going fast is much greater than at the stern.

Third, most ships pitch on a pivot abaft the centre, consequently there is more vertical motion at the bow than at the stern.

I think, therefore, that my diagrams give a fair idea of the area of vital target in each ship in ordinary weather; say, with the force of wind from 4 to 5. If the weather is rougher, it will be still more in favour of the merchant ship. If smoother, it will be in favour of the cruiser; though even if it were a flat calm, it appears to me that the white bow wave of the cruiser would be an excellent and attractive mark to fire at. And before going on to my next point, I may here observe, with reference to this bow wave, that although, so far as I am aware, no experiments have been tried by firing shot into the great white curl of broken water at the bow of a ship proceeding at speed, there seems to be good reason to suppose that a shot from a rifled gun would penetrate it, and also the thin steel beyond it; in which case the ship would certainly have to stop at once.

The difference of the area of the two targets depicted in Figs. 1 and 2 only represents the smallest part of the advantage which the chased ships will have over the chaser; and we have next to consider the nature of the wounds (or, in other words, the shape and direction of the holes) which each ship can inflict on the other, and the effect which such holes will have in stopping either ship.

Fig. 3.

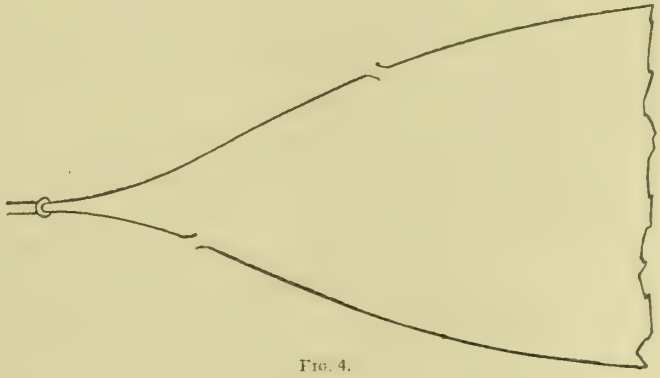


Fig. 4.

I have seen some experiments made with ordinary small rifled shot against thin steel plates, and I think Figs. 3 and 4 give a very fair representation of the nature and direction of the holes which each ship might hope to make in the other, always remembering that the hole will be very much larger than the shot that makes it. Thus a 4-in. shot might be expected to make a 6-in. or an 8-in. hole, with jagged and most

irregular edges; and striking as it must do at a small angle when ships are end on to each other, it is obvious that it would make a scoop-shaped hole such as I have endeavoured to depict in the diagram; and I submit that it must be equally obvious that the effects of such holes in the bow and stern targets which I have sketched in Diagrams 1 and 2 must be totally disproportionate. Thus, while a hole of that nature in the bow of a ship would scoop the water up with very great force if she was proceeding at high speed, and certainly oblige her to stop before she could attempt to deal with it, a hole of the same nature in the quarter, with the mouth of the scoop pointing aft, would do nothing of the sort, and the faster the ship went the less water would get in, and the easier it would be to deal with it in the way of plugging.

There has not been much experience with the wounded water-lines of iron and steel ships, and there seem to be great difficulties in the way of making practical experiments; but I submit that the assumptions I have set forth are in accordance with the ordinary laws of hydraulics. If there is any serious flaw in my line of argument, I beg that it may be pointed out; but if not, I think we are justified in saying that, the object of each ship being to stop the other, the chased ship has very great advantages over the chaser.

I alluded above to the question of steering gear; and that, of course, is the weak point in the merchant ship, as her wheel-house is greatly exposed. But it seems to me that this might be abandoned and disconnected, and the ship steered temporarily, and with sufficient accuracy, by luff tackles on the chains or rods in the waterways. The rudder itself is a very small object to hit, and as to the screw, even if it were struck, and one of the blades shot away, it would not matter much, as there are plenty of instances of ships breaking their screws in the Suez Canal, and steaming nearly as fast with two blades as they did before with three or four.

It has been suggested that if a large merchant steamer is attacked by a small cruiser, she should try to ram and run over her small opponent. Such tactics, I believe, would be utterly mistaken, as in all probability she would not succeed in ramming her, and all the time she was trying to do it she would be exposing her most tender and vital parts, viz., her thin iron bow, to shot holes, one of which near the water-line would force her to stop her engines.

It would not be proper to raise any discussion in this Institution upon questions of international law; as to the right of a merchant ship to defend herself; or what authority the blue ensign or R.N.R. after the captain's name may give her in this direction. These questions must be settled elsewhere; and we can only hope that those who have the settling of them on our side may be blessed with sufficient wisdom not to settle them in the shape of a noose for our own necks.

That the officers of the merchant service will be ready and willing to fight, we have only to look at such papers as that lately read by Captain Caborne, R.N.R., at the Royal United Service Institution, and another of the same nature by Captain Crutchley, R.N.R., last year, to prove; by these it will be seen that they are only too anxious to prove that they do not consider "R.N.R." as a mere honorary title, but are ready to take an active share in the defence of the Empire; of which the protection of the mercantile marine is one of the principal items, if not absolutely the most important; and when we come to consider that the alternative to fighting will be the inside of a foreign prison, or a voyage on the Atlantic in open boats, we can have little doubt but that their crews will support them heartily.

The story of "Jack the Giant Killer" is a very pretty fable for children, and so is the supposed capture of the *Umbria* by the *Sandfly* at last year's naval manœuvres. But if ever such a thing takes place in actual war, it will be entirely our own fault for not taking very simple means to prevent it.

I need not enter into closer details in the matter, or point out that if the cruiser has only a slight excess of speed and does not sight her prey very early in the day, the latter will have a good chance of escape at night by putting out her lights and altering course.

No doubt also many other additional methods of protection for a merchant ship making a runaway fight of it will suggest themselves to the fertile brains of shipowners and others. I have only suggested what seem to me to be the very decided advantages which a thin-skinned iron or steel steamer, bent on getting away, will have over another of similar construction which is trying to catch her, notwithstanding that the latter may be much more heavily armed; and it may be noted that even our own so-called belted cruisers have scarcely any protection against the peculiar injuries to which I have alluded, and which I think so extremely likely to take place under the circumstances. I have purposely avoided discussing the effect of shell fire; but it does not appear to me that even the use of high explosives will vitiate my argument, or interfere with the fundamental principles upon which it is founded.

DISCUSSION.

Mr. James Dunn (Member of Council): I would ask Captain FitzGerald to accept my thanks for his very interesting and able paper on the protection of the merchant steamers of this country. This, my Lord, as you know, is a subject which has been frequently dealt with here. Many times it has been under discussion, and so important is it that I have no doubt from time to time we shall have to give further consideration to that subject. Reference has been made here to-day to the food supply of the country. The food supply of this country is of unparalleled importance. Its close alliance to, and its dependence on, the mercantile marine, is a fact which cannot be doubted. Therefore, the safe guardianship of the Mercantile Marine is of paramount importance. Our military and civilian

experts agree that the British war fleet, powerful as it is, would not alone be powerful enough to ensure the safe transit of British goods, carried as they are over every ocean in the world by millions of tons, in thousands of ships. We hear a very great deal about the increase in the war-ships of the Navy, but after what has been said here this morning, it is not for me to say that if we get this larger number of specially built fighting ships roaming the ocean, they alone will be able to afford the whole of the protection to our commerce which will be required, but we shall have to seek the aid of these splendid ships which are placed at the service of the State through the patriotism of the British merchant. Not, as Captain FitzGerald has pointed out, that these ships can be looked upon as regular war-ships, but they can, by carrying guns, be made able to protect themselves against the ships to which you so aptly referred yesterday, my Lord, as "commerce destroyers." They can defend themselves, and they can defend their more helpless fellows, against the attacks of similarly improvised ships, which will no doubt be put on the ocean by our enemies for the purpose of destroying our commerce. That such a fleet is within reach, and that it is possible to give a measure of offensive and defensive power to the merchant ship, is a reality; and it is no secret, no breach of confidence on my part, when I say that the Government has recognised the fact that the merchant ship is a factor of more or less power in the defence of British interests. We have only to refer to the later numbers of the "Navy List" to find included the names of the swiftest steamers in the world, all of which are placed at the disposal of the Admiralty; and it is no secret either, the fact having been mentioned in Parliament, that provision has been made for arming a very much larger number of ships than those whose names appear in that List—ships that perhaps would come under the category of what Captain FitzGerald calls the second or third class; but second or third class only, I would venture to suggest, in the fact that they have not power to steam at as high speeds as the ships whose names are given; and I think that that fact must be borne in mind when we are dealing with this question. When we talk about a hole being made in the bow of the ship into which the water will not enter, you must, if you can conceive such a thing possible in a hole so situated, be dealing with a very fast ship. Your ship must be going through the water at a very great rate for the water to stop outside. We have here to deal with the arming of second and third class ships, which will only steam perhaps at the rate of ten or twelve knots per hour; though I take it that, except in respect of inferior speed, these ships cannot be called second or third class, because in them all we must insist upon one condition—a most important condition—and that is, that the ship should be efficiently subdivided into water-tight compartments. We can have a very large number of ships of this class—not only the forty or fifty referred to by Captain FitzGerald, but I may say ten times forty ships that are efficiently subdivided into water-tight compartments, which are structurally strong enough to carry guns. I cannot agree with Captain FitzGerald, where he says, in page 246, that no matter how many compartments a ship may be divided into, two or three shot-holes in the neighbourhood of the water-line will either disable, capsize, or sink any steel or iron built ship; but I think, so splendidly subdivided now are so many of our merchant ships into thirteen, fourteen, or even fifteen water-tight compartments, that they would survive and show a bold front to the enemy even after the gunner had done his worst. It may be said to-day, as it was said yesterday, that this was only a matter of opinion, and that we have had no experience in respect to this matter. Let that be so; I will still contend that we ought to "play for safety," and that we can "play for safety," by arming only these efficiently subdivided ships. Although I have differed from Captain FitzGerald in this matter, I am prepared to go with him in most of the other suggestions that he has made in his paper, that is, so far as they relate to the offence and defence of the ship. I shall not attempt—I will not presume to follow—Captain FitzGerald in giving my

opinion, founded on experience, as to what part of the ship is most likely to be hit when she is pitching or 'scending. I have been to sea a good many times, but I am bound to admit that during this pitching and 'scending operation my observations have been of the very feeblest kind; I have been almost helpless, but I have sometimes seized the opportunity to look over the bow, and I have had opportunities of conferring with nautical men, and I am more than glad to learn to-day from so experienced an officer as Captain FitzGerald that his observations have led him to make suggestions—suggestions which have followed the earlier observations of other people, so that his proposals have been already adopted, and have actually been put into practice by other people. Captain FitzGerald says, on page 245 of his paper, that his proposals are simple and inexpensive, and can be carried out in all merchant steamers. In that I agree with him. His first suggestion is to build an athwart-ship coal bunker abaft the engines, as a protection for the engines against the bow chasers of cruisers. It is now a matter of history that in the year 1885 there were fears of an event that happily never took place, I mean war with Russia, and it is a known fact that the British Government at that time chartered a large number of merchant steamers, both at home and abroad, and turned them into fighting cruisers, and put guns into them to enable them to defend themselves when carrying troops or when carrying stores. A number of those ships were taken up in Liverpool, and I shall be borne out by my late chief, Sir Nathaniel Barnaby, in stating that these ships had means of defence given to them exactly on the lines now suggested by Captain FitzGerald. These ships all had a solid block of coal built abaft the engine-room, going right across the ship, and, further than that, they had a solid block of coal built at the forward end of the boilers going right across the ship to protect the ship from the stern fire of an enemy; and, more than that, there was a solid block of coal running along the side of the ship throughout the length of the machinery and boiler spaces for the sake of giving protection against the broadside fire of an enemy. Now, Captain FitzGerald's second proposal is to have mountings and fittings for two light guns, say 4-in. guns, right aft, one on each quarter. Well, my Lord, it will be of interest to this Institution to know that these cruisers did in 1885 carry two 5-in. guns right aft on the quarter for the sake of firing at the ships that were chasing them, and, further than that, they did actually carry two 5-in. guns right forward on each bow to be used when chasing; and they did more than that, for they each of them carried either two or four light guns on each side to give them an opportunity of punishing the enemy whenever occasion offered.

Captain C. Penrose FitzGerald, R.N. (Associate): Mr. Dunn must excuse my saying this is entirely beside the question. I exclude those regularly armed ships. The ships I am speaking of are quite different. The ships Mr. Dunn is speaking of are not merchant ships, but cruisers, intended to be used in time of war. In my paper I have nothing to do with the armed cruisers. I think the speaker mistakes my point.

Mr. James Dunn: I may say at once, my Lord, that I am not dealing with the armed cruisers. A few of the ships were specially armed cruisers, taken up to be used as armed cruisers, but I think I explained just now a large number of ships were taken up, merchant ships, ships that carried stores and provisions and troops, and in those ships these means of offence as well as means of defence were provided. Captain FitzGerald, in his paper, goes on further to say that he does not propose any protection for steering gear; that, he says, would be too complicated, and the steering gear must take its chance, but he does not seem to think that the loss of steering gear would necessarily stop the ship; he would keep the stern to the enemy, and even if the rudder were hit, which is a small object, or one of the blades of the screw were shot away, he says it would not matter much. The steering gear, he says, might be abandoned and disconnected, and the ship steered temporarily and with

sufficient accuracy by means of luff tackles connected with rods and chains running along the water ways. I may say that this question of steering has been a very difficut problem whenever we have considered the question of putting guns on board ships. But the time came, four years ago, when we actually had to grapple with the subject, and it was then resolved that when a ship had a steam-engine we should put coals or armoured plates round that engine and round the steering gear. But it was felt that that was a very incomplete defence, and that the time might come when you would have the steering gear cut adrift or your steam-engine disabled, so that it was resolved that we should attach chains to the after part of the rudder, that we should carry those chains up past the quarter, and then, by means of luff tackle, work them on the deck along the side of the ship just on the plan now apparently suggested by Captain FitzGerald. I have merely given you, my Lord, these facts as a matter of interest; and I would say, in conclusion, it is very gratifying when we find that so distinguished and experienced an officer as Captain FitzGerald concurs, and as the result of his own observation has recommended plans to be adopted, such as the Admiralty in times past have made it a rule to adopt.

Rear-Admiral P. H. Colomb (Associate): My Lord, on the question now before us, I think most of us have felt that the remarks of the previous speaker were properly taken exception to by Captain FitzGerald, because the protection he was asking for was the protection of merchant ships, not ships which had passed from the Mercantile Marine into the hands of the Government. His proposal, as I take it, was a proposal to be carried out by the owners of merchant ships in time of war. He made a very interesting remark as to the pitching and 'scending of ships. I hope that some naval architect who has studied the question will be able in following me to state what the scientific view of that question of pitching and 'scending is. I myself am not prepared to go so far as Captain FitzGerald has gone in supposing that a ship will expose much more of the surface below water forward than she will expose aft. I am not prepared, in fact, to go so far as to say that the diagrams given in Figs. 1 and 2 represent the exposed target correctly. So far as regards the two proposals, the coal wall abaft the engines, and the guns mounted aft, I fancy all connected with the sea must be in agreement. The tatics of the merchant ship must be to run away, and the protection she requires will be protection at the stern, and not necessarily anywhere else. She need not inconvenience herself by attempting protection in any other direction. And in this connection I may remark that history is in all cases the true guide upon these questions, and that the proposals for mounting of the guns specially aft, which are made by Captain FitzGerald to-day, were made about eighty years ago, and very fully considered as an alternative to convoy. It was recommended in 1811 that the fast merchant ships, instead of depending upon convoy, should depend for their defence upon light guns mounted in the stern. I presume that even if the cruiser is naturally the faster ship she would not turn out to be the faster ship in chasing, on account of her shortness, which would allow the sea to stop her, and that, therefore, the merchant ship would have the opportunity of disabling her if she kept up the chase long enough. I do not think, by-the-bye, that anybody but Captain FitzGerald would have given such admirably suggestive names for his vessels as the *Corn Bin* and the *Rat*. The question of compartments has been alluded to. It is a point upon which for many years I have felt strongly, and the Admiralty have had from me in times past, as I think Mr. White probably knows, very strong letters upon the trust which we are inclined to repose in compartments which are not absolutely water-tight; but if you could and if you did construct large numbers of compartments which had no removable communications with the next compartments, then I think the trust which Mr. Dunn is inclined to repose in them might be justified, but I am afraid we have had a recent and very sad example of the truths that we must not altogether trust in the security of compartments

which have removable openings with other compartments. That I take to be what Captain FitzGerald means when he says he does not place implicit confidence in the water-tightness of compartments which are supposed to be water-tight. But there is the question as to the effect on a merchant ship of being chased, and as to what would cause her to surrender, which has been previously alluded to by me. I think it does not quite follow that it is the destruction of the structure which would bring about the surrender. I most fully agree with every word that Captain FitzGerald has said with reference to the pluck and determination of the Royal Naval Reserve and of the merchant service generally. Their pluck and determination is historical. I am quite sure that our men now are the same sort of men as they were in the old days. But you have to recollect that a merchant ship is a trust reposed in the captain of the ship with limits. He is not, for instance, compelled to run great risks to life to save what is merely money or material. And, therefore, I think that those who contemplate the possibilities of war in the building of new ships, should, if possible, as well as securing the structure, enter upon the consideration of giving some slight security at any rate for those who are directing the course of the merchant ship. There is only one further point, and that is the right to defend the merchant ship. The question was asked a year or two ago, and answered by Lord Thring, who is a perfectly competent authority, I think, on the subject.

The President: That is a legal question which, I think, is hardly within the scope of the discussion.

Rear-Admiral Colomb: As it was alluded to, I wished to remark on it, but I bow to the President's ruling.

Mr. W. Baden-Powell (Associate): My Lord and gentlemen, this is a subject which I think affects the country quite as much as the battle-ships, which we were so pleased to hear all about yesterday, and which the country appears to have taken with the greatest kind feeling. Now, the protection of our food supply is a question of importance which Members of Parliament, in addressing their constituents, so far as I have been able to read and hear them, have almost entirely left out in the cold. Indeed, I was extremely surprised the other day to hear, in the House of Commons, when I was visiting there, a member for the working men get up and grumble at money being invested in the protection of our commerce and country, saying that it was putting a charge on the working man. Now, the working man would be the first to suffer if our food supply were checked in the slightest degree by hostile cruisers in time of war, therefore it seems to me that every proposition that can be brought forward by practical seamen and naval architects, with regard to securing that supply flowing in unfailingly, must hold the mind of every thinking man in this country. Having had some experience myself in the handling of these ships at sea, I have over and over again turned in my mind how can that ship or any ship that may be built in the future be protected against the gun fire of a fast cruiser. I quite agree with Captain FitzGerald in most of the suggestions in his paper, but I disagree entirely in one, and that is that the steering gear may be left out of the question at present, as being too complicated. I think the steering gear is the very point, next to the steam pipes, which the enemy would attack. So far as my experience goes, with the exception of a few small coasting steamers, the neck of the rudder, and the steering gear of every ship in the merchant service is not only above, but considerably above the water-line; and whatever the effect might be—an artilleryman would be able to tell us—of the small shells or shot from the new "quick-firing" guns, I have not a doubt myself that one or two plugged into the stern would very soon jam that steering gear; and as soon as that steering gear is jammed—the men on the ship being very few in number, and only one or two to be spared to set her to rights—you would have the ship running

round and round in a circle, and the cruiser could cut her off as easily as does a greyhound, doubling a hare in the Waterloo Cup coursing. Then, with regard to the question whether the steering gear cannot be protected by coal bunkers, and as to there being coal-bunkers across the shaft abaft the engines, I cannot see why coal-bunkers should be necessary for an ordinary merchant ship, because she would probably have cargo up to her upper deck, and she would be full up abaft the engine-room. Most of the ships now carry their officers' quarters under the bridges, and the consequence is that most of the after part of the ship might be filled up, and that a shell might enter the cargo and set it on fire, and do some damage there, although I doubt its traversing through the whole of the after-holds and into the engine-room. However, the bulkhead of coal is a grand suggestion, but it is only a question whether in peace time the ordinary shipowner who studies his pocket will go to the extra expense of creating bulkheads which may probably be useful only in time of war. I think he will consider the other alternative, which is to place his ship under a neutral flag in time of war. ("No.") That causes a difference. So long as the Declaration of Paris, which we have been told is not to be alluded to here to-day, stands, it becomes a question for every careful shipowner to think, "Will it pay me better to run the risks of war, and pay a high war premium, than to go for a time under a neutral flag?" Now, will the enemy always chase astern? That is another question. We assume the speed of the enemy is only two knots better than that of the merchant ship. I should say that the enemy would be probably capable in time of war of putting upon the ocean as fast a cruiser to chase the merchant ships of England as we can put, or, at any rate, he would approach it very nearly. Such vessels as the *Esmeralda* or some of that type that can go their eighteen knots. Put it down at fifteen knots head to sea, or fourteen, or even thirteen, if you will, still you have the advantage of the ten-knot merchant ships, because nine out of ten do not make a sea-going speed of more than that. Then we have the old weather-gauge that Lord Charles Beresford alluded to yesterday. May not the cruiser pick up his merchant ship from to windward? How is the merchant ship going to steam head to wind to get away? The cruiser could take up the fighting position if he had the weather gauge, and he would probably come down on the beam of the ship, and put one shell into the steam pipes of the merchant steamer, and there would be an end of her, and she would have to cave in. It has been suggested that these merchant ships should be armed with two 4-in. guns right aft. I presume that the ships would be built up to the strength requisite for it, but I cannot understand myself, having had some little experience of gunnery, how the crew are going to work those two guns with anything like one shell or more bursting on the ship from the bow guns of the cruiser, because it seems to me that the gun's crews would be swept away, and the ship's crew, being of limited amount, as I said before, eight or ten men on board one of these ships, which could not be increased in war time, I expect, because you would not find men to man the ships—they would not be able to replace one another at the guns, and the consequence would be either a mutiny, or the demoralisation of the crew, and the ship would have to haul down her flag. I have thought of this matter very carefully in regard to what we call tramps—the cargo carriers, and, I think, the less said about their fighting the better; if they can run and protect themselves, so much the better for them. It is quite another matter with regard to the "armed mercantile cruiser;" part of her business would be to fight and to return the fire, and to try, if possible, to disable her enemy; but I think it would be simply throwing the men's lives away to place them on the ordinary poop of a merchant ship, and to allow the enemy's cruiser to pop at them with quick-firing guns. These observations occurred to me with regard to this paper, but still I must say that I am strongly in favour of Captain FitzGerald's suggestion, and I hope that naval architects will give the subject careful consideration, because it will be one of first importance immediately war is declared.

Mr. Henry F. Swan (Member): My Lord and gentlemen, I have not much to say on the subject, but there is one point Captain FitzGerald has laid great stress upon, and that is having a block of coal abaft the engine-room. I must confess I do not see the advantage of that. We are dealing now with merchant vessels, which must be either in a laden or an unladen condition. If laden, the cargo would afford protection the same as a block of coal would do. If they are empty, a shell from a chasing cruiser would simply go clean through the after-hold, and destroy the shell of the ship and sink her rapidly. Therefore I attach great importance to what Mr. Dunn has said about the necessity for greater subdivision. Admiral Colomb has rather deprecated the possibility of making bulkheads absolutely water-tight.

Rear-Admiral Colomb: I beg to interpose the remark; I distinctly guarded myself against that. I understood you did not, in fact, make them water-tight, but you had removable openings. That is quite different.

Mr. Henry F. Swan: There is no necessity in ordinary merchant vessels for movable doors or other openings in bulkheads. In such ships as are being built now, the bulkheads are being made absolutely tight, so as to withstand any pressure brought against them, and I would just go on to say, following up what has been said as to subdivided ships, that you thereby provide the means immediately on war being declared, or on your wishing to convert the merchant ship into a cruiser, of filling any of the compartments with water, which is in itself an excellent armour, or, if you wish it, you can fill between the after engine-room bulkhead and the next bulkhead with coal, and thereby obtain the block you wish. A merchant ship, for instance, that is carrying 3,000 or 4,000 tons, can easily afford to have even 1,000 tons of cargo capacity filled in with coal in that way, in order to obtain the protection which is desired both before and abaft the engine-room.

Mr. J. H. Biles (Member of Council): My Lord and gentlemen, I should like to make one remark. Captain FitzGerald makes a statement here upon which I should like to join issue with him. With reference to the forty or fifty first-class steamers, he says, "I will pass them by, merely observing that, although I think the precaution of arming them an exceedingly wise one, I do not think their proper function in war time will be to act as regular men-of-war cruisers, for which they are ill-suited," &c. I think the point is well worth consideration, whether these large ships, some of which are running in the Atlantic trade, would not for purposes of war cruisers be much better than many of the smaller war ships that are in existence, and that fly the flag of the British Navy at the present day. Though they have the disadvantage of being large targets, and of not being perhaps so minutely subdivided, and of being larger, and therefore not so capable of easy manœuvring, yet in average moderate weather they have the advantage of being able to maintain a speed which the shorter cruisers—I mean the cruisers of 250 ft. long, and less—could not possibly maintain; and they have the advantage, if they are properly designed, of being able to carry a large number of guns; and that will, to a large extent, in my opinion, counterbalance the fact that they offer large targets, and that they have not quite such a minute subdivision. But, though their subdivision is not so minute in absolute size, yet in relation to the size of the ship I think it is quite possible to arrange these vessels so that they will be quite as efficiently subdivided as most of the modern cruisers. For my own part, if I were a naval officer, I think I would as soon fight in a ship like some of the larger ships which have recently been turned out, with ten or twelve guns on their deck, having regard to the high speed they can maintain, and the coal protection that can be given them, and the fact that the boiler and engines are below water and well surrounded by coal bunkers—I would rather take my

chance in a vessel of that kind than in most of the ships in the British Navy which are under 3,000 tons displacement. There is another advantage they would have, which is a very important one, and that is, that in moderate weather they would be much steadier gun platforms, and would therefore have more chance of hitting the small cruiser than the cruiser would have to hit them, and I think they should not be despised as real war cruisers in time of war. If they have, as some of these recent vessels have, their steering gear under water, and a large rudder area, so that they can turn a complete circle in five or six minutes, they should be equal in manœuvring qualities to most of these cruisers. Admiral Colomb says unless you have bulkheads which have no openings in them, or bulkheads which are not removable, you have not a safe ship. In many respects I quite agree with him, and I think the tendency of our modern passenger ships is in the direction of having no doors; the latest practice in that direction certainly points that way. But while that is true, there are many cases on record in the papers of this Institution of vessels with doors in their bulkheads, which have been saved by having the bulkheads in spite of the doors, because there is generally some time to shut the door. But, at the same time, if you wish to have a ship upon which you can thoroughly rely, and not have to depend, when an emergency comes, upon some human being who will lose his head, or be overboard at the required time, then you must have a ship divided into bulkheads without doors in them. I think the suggestions made by Captain FitzGerald in his paper are admirably adapted to the purpose which he has in view. The pith of the whole paper lies in the fact which he, with his usual acuteness, has discovered, that the chased ship has enormous advantages over the chaser. He says that such holes as the chased ship may get in her will not be likely to seriously impede her speed. This is quite true, and we must also remember that the cargo ships he is dealing with will have their holds largely filled with cargo, which will probably be water excluding. Captain FitzGerald says, moreover, that a rifle bullet will be likely to penetrate the bows of a cruiser. I have seen a rifle bullet fired at some of their plates, and I am certainly of opinion that the ordinary cargo ship would certainly not be penetrated by it; and, of course, an ordinary cruiser would not be penetrated by such a very small shot. It will take at least a three-pounder to get through it under the ordinary conditions of one ship chasing another.

Captain C. Penrose FitzGerald, R.N.: I did not say anything about a rifle bullet.

Mr. J. H. Biles: Then I beg Captain FitzGerald's pardon. I may have made a mistake; but I understood that in reading the paper that he did say so. But I think he has done us a great service in calling attention to the way in which merchant ships may readily be protected.

Mr. B. Martell (Vice-President): I have only a very few remarks to make, my Lord, in view of the time and the number of papers that are to be read; but I think the thanks of this Institution are greatly due to Captain FitzGerald for having come forward in the manner he has, to suggest what can be done for the benefit of the Mercantile Marine of this country. When naval officers take up questions like this, and bring forward their views in this manner, so that they can be discussed, it is very evident that they are doing much good, and they should be congratulated upon doing it. There are two or three remarks only that I have to make, and one is, that I want to endorse the view put forward by Mr. Baden-Powell. I cannot see, to begin with, the necessity of putting any guns whatever on board our ordinary mercantile vessels, because, as he has very properly said, these ships are built for cargo purposes, to go at a speed of something like nine or ten knots, as a rule. Well, with vessels of that speed, what is the use of arming them against these fast vessels, that may be, and no doubt will be, specially provided by other countries, and have, also, a much superior armament? The fact is,

that if you were to place guns on board vessels of this kind, I fear that, with the great courage that Britons are known to possess, having guns on board, they would want to use them. And if they used them, I can only say that they would come to grief in ninety-nine cases out of a hundred. Therefore, I would not tempt them. I think it would be most unwise, and even cruel, to put on board of these comparatively slow vessels, guns which they would think it their duty to use when they were chased, because I think it would be leading them into great unnecessary danger, without any chance whatever of their succeeding in escaping. I do think that the action of the Admiralty, in taking up those very fast splendid ships in the manner they have, is most commendable; and I am glad of this opportunity of expressing what I think should be expressed in a more certain manner than it has been expressed, and that is, the thanks of the Admiralty to begin with, and of the country afterwards, to Mr. Dunn, whose remarks we have heard with so much pleasure, for the great energy he displayed, and the intelligence shown by him in going round collecting information, and arranging it in the manner he did, as to ships in the Mercantile Marine that would be useful for purposes of this kind. I remember going down to Liverpool, and seeing one of these ships armed and fitted up with guns on board, and I had an impression that in such a ship as that I should not fear to cross the Atlantic myself, let me come into contact with whatever vessel I might. I think such ships as that are capable of doing an enormous amount of good. I cannot say more about them, because Captain FitzGerald says they do not come under notice; he leaves them out. With regard to the others, with all due deference, and with great thankfulness to Captain FitzGerald on the part of the Mercantile Marine, I think he might just as well have left them out as well, because I think if we were to attempt to do anything with regard to them, we should only be doing an injury instead of doing any real good. They must just take their chance, and to attempt to arm them for the purpose of defending themselves against fast-sailing cruisers would be a very great mistake, as I have said before, and lead to loss of life, without doing any good in the saving of the ship and the lives of those on board. With regard to one remark of Admiral Colomb, I should merely like to say that I do not advocate the piercing of bulkheads, because we aim at perfection, as nearly as possible, those of us who have to deal with these subjects. I should like perfect bulkheads, without being pierced. But, at the same time, we have to consider the exigencies of trade. Merchant ships are built for the purpose of returning some interest to those who invest their money in them. Therefore, we have to look to the exigencies of trade to some extent, and the exigencies of trade require that in some instances you must have the bulkheads pierced, and have a door in them. The question is how to have a secure door, and naval architects know how to do that. They know how to make a door perfectly secure. We know of many instances where doors in bulkheads have been closed in times of danger, and ships have been saved; and, with the means we have in the present time of securely closing doors of that kind, we are obliged to defer to the exigencies of trade, and to allow these doors occasionally to be formed in bulkheads, particularly as it has not been shown that practical danger results from it.

Rear-Admiral Colomb: May I just point out, my Lord, that I never suggested that things should be different from what they are now? All I said was that experience showed that you could not trust to bulkheads with openings in them as they exist at present.

Captain C. Penrose FitzGerald, R.N. (Associate): The President has desired me to be short, and I will obey orders. I do not enter into the discussion of the minor points, except to say that I have been rather misunderstood. Some of the speakers have not grasped what I meant. The only person who fairly joined issue with me was Mr. Martell, and he has fairly met the principal point which I

raised. The other gentlemen have all been talking about the large armed merchant cruisers on the Admiralty List, which do not come under my notice at all. I am quite content to let these misconceptions pass; but Mr. Martell comes straight to the point, as he always does, and says my proposition is no good; he says we do not want to fight. He has plainly put it that he does not think the merchant shipowners can afford to sacrifice the space for cargo, if I understand him right, to put a small wall of coal abaft the engines. That is their business; if they do not like it, let them leave it alone. My own idea is that if you do come to war, you will not be content to see your trade passing under a foreign flag. That is a proposition I do not believe in. I believe you will be straining your minds to think how you can protect your ships. You will have a captain, who will say, "What am I to do if I am chased?" You may not be chased by a *Piemonte* or a *Dupuy de Lôme*, but by some twopenny-halfpenny craft with one gun; and why not try to stop her? I do not want you to fight a line-of-battle ship with a merchant steamer, but I say that two guns in the stern and a coal bunker abaft the engines, and a man who will fight her up to a certain point, may have a good chance of putting a shot in the right place that will stop the cruiser, and certainly he has a better chance of stopping her than she has of stopping him, and that is the whole gist of my argument.

The President: Gentlemen, I am sure you will wish me to thank Captain FitzGerald for his very valuable paper. We are always glad to hear Captain FitzGerald, who generally amuses us, and who generally says something that we never heard before. I should like to add just this one remark on his paper. I am afraid it will not receive the general popularity that its importance deserves, because it is practically a paper on the art of running away, and that is not an art which the English people ever practised, or, I think, ever will. It is a most important question which has been brought before us and discussed, whether it is wise to put guns on board merchant ships, because, depend upon it, if you do, the sailors will always use the guns which you put there. I think probably the best thing she can do will be to try and run away. That is really the object of the paper, and perhaps it will not be very much liked on that account. We thank Captain FitzGerald, and now we will proceed with the very interesting paper of Mr. Watts.

THE ITALIAN CRUISER "PIEMONTE."

By P. Watts, Esq., Member of Council.

[Read at the Thirtieth Session of the Institution of Naval Architects, 11th April, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

By the kind permission of the Italian Admiralty, I am enabled to place before you some particulars of the Italian cruiser *Piemonte*, constructed by the firm of Sir W. G. Armstrong, Mitchell & Co.

This vessel is the latest of some dozen vessels of the protected cruiser class, built by the same firm, including the *Esmeralda*, built in 1882-3 from the designs of Mr. George Rendel; and the *Dogali*, built in 1886 from the designs of my predecessor—Mr. White.

Lord Armstrong, who has for several years past strongly advocated the construction of this class of war-vessel, has enumerated as their chief features, "Great speed and nimbleness of movement, combined with great offensive power," and "little or no side armour, but otherwise constructed to minimise the effects of projectiles"; and in the design of the *Piemonte* it was my endeavour to develop these features as much as possible, with the conditions that the displacement was not to exceed 2,500 tons, and the speed was not to fall short of 21 knots with forced draught.

The principal dimensions, weights, &c., of the vessel are given in the Table on page 266; and Figs. 1, 2, and 3, Plate XXVII., show the profile, plan of weather decks, and the midship section. She is 325 ft. long, 38 ft. broad, and 15 ft. mean draught, and her displacement is 2,500 tons; she has a steel protective deck with sloping sides from stem to stern, which is 1 in. thick along the middle, and 3 in. thick on the slopes; her armament consists of—

Six 6-in. quick-firing guns,
Six 4¾-in. ditto,
Ten 6-pounder Hotchkiss guns,
Six 1-pounder ditto,
Four 10-mm. Maxim guns,
Three torpedo tubes;

and her estimated speed is 21½ to 22 knots.

Four of the 6-in. guns, and the six 4¾-in. guns are carried upon the upper deck, the 6-in. guns being sponsoned out so as to enable the two foremost to fire right ahead, and the two aftermost to fire right astern; one of the remaining 6-in. guns is placed on the forecastle, and the other on the poop. All of these guns have considerable arcs of training, as indicated upon the plan of weather decks, Fig. 2. Four of the 6-pounder quick-firing guns have right ahead fire; two of these are placed under the forecastle, and two upon the after end of the forecastle; and four of these guns have right aft fire, two being placed under the poop, and two upon the fore end of the poop. The other two 6-pounders and two of the 1-pounders are placed on the topsides. Each of the two lower tops carries two 1-pounder Hotchkiss guns, and each of the two upper tops two 10-mm. Maxim guns. One of the torpedo tubes fires directly ahead, and one fires on each broadside from a torpedo chamber immediately before the machinery spaces.

I may remark that provision was also made in the design for a torpedo chamber immediately abaft the machinery space provided with a training tube on each broadside, and also for a torpedo tube at the stern firing right aft, but the Italian Admiralty have recently dispensed with these, accepting other armament weights in exchange for them.

This distribution of the gun armament has great advantages; it has been followed in most of the cruisers built by Sir W. G. Armstrong, Mitchell & Co., including those built before the *Esmeralda*. The guns upon the poop and forecastle have considerable arcs of training on each broadside without interfering with the fire of any of the other guns. Four 6-in. guns, three 4¾-in. guns, five 6-pounder Hotchkiss guns, five 1-pounder Hotchkiss guns, and four 10-mm. guns can be brought to bear upon an enemy on either broadside; and three 6-in. guns, four 6-pounder Hotchkiss guns, two 1-pounder Hotchkiss guns, and two 10-mm. Maxim guns can be brought to bear upon an enemy either right ahead or right astern.

The 6-in. and 4¾-in. guns are provided with 4½ in. steel shields for protecting the gunners, and all of the other guns carry light shields for the same purpose; and the torpedo tubes are encased in strong armour tubes.

The *Piemonte* is the first vessel armed with the new Elswick quick-firing gun, all of the 6-in. and 4¾-in. guns being of this pattern.

Lord Armstrong, in speaking of this gun recently, said: "The advantage of being able to fire rapidly at critical moments must be obvious to all. In the first place, the increased rapidity of the fire of each gun is tantamount to increasing the number of guns, without necessitating a corresponding increase in the number of gunners, or in the collective weight of the shields required to protect them. In the second place, we

obtain the great advantage of being able to repeat a successful shot before the enemy can materially change his position, which would render necessary a fresh adjustment of the gun. These salient advantages have been fully realised in our new guns of 4¾-in. and 6-in. calibre, with both of which a rapidity of fire has been obtained hitherto considered impossible with guns of so heavy a nature. Great simplicity of design and strength of mechanism have been combined in the construction of these guns and their carriages; and with the improved descriptions of powder now coming into use, velocities have been obtained so great that the 4¾-in. gun, weighing only 2 tons 1 cwt., is capable of piercing 10½ in. of wrought iron, while the 6-in. gun, weighing 5 tons 15 cwt., can pierce 15 in. of the same material, muzzle velocities being taken in each instance.

"These guns are mounted on specially designed shielded carriages, in which exceptional facilities in handling and aiming have been combined with great protection to the gunners, and in the numerous trials carried out the shooting has been characterised not only by rapidity, but by unusual accuracy.

"The comparative rates of fire of the present breech-loading service guns, and of our new improved guns, may be judged by the following instances. In some trials carried out last year with our 4¾-in. gun by the Admiralty, ten rounds were actually fired in 47½ seconds, whereas an ordinary breech-loading gun of the same calibre, firing in competition, took 5 minutes and 7 seconds to fire the same number of rounds. Again, the great accuracy of the guns, combined with rapidity of fire, is illustrated by the fact that five rounds were fired a few weeks ago at Shoeburyness, in which, at a distance of 1,300 yards, a target of 6 ft. square was hit five times running in 31 seconds."

Speaking of the *Piemonte* on the same occasion Lord Armstrong said: "She will be capable of discharging against an adversary in a given time twice the weight of shot and shell that could be fired by the largest war vessel now afloat, not excluding the leviathan battle-ships of five or six times her size, which could ill withstand the torrent of shell which the *Piemonte* could pour into the large unarmoured portions of their structure."

The engines and boilers are wholly below the water-line, and protected by the armour deck; so also, of course, are the magazines, steering gear, &c. The level of the armour deck throughout the length of the ship is shown on the profile, Fig. 1, the dotted line indicating the deck at middle, and the through line the deck at side. All apertures through the armour deck which would require to be opened in action are provided with cofferdams rising four feet above water, and all openings are fitted with armour covers or armour bars.

Both below and above the armour deck the ship is subdivided into a large number of water-tight compartments. Each set of engines is in a separate compartment, and

each pair of boilers is in a separate compartment. There are a series of water-tight flats forming an inner bottom throughout the ship, except in wake of the boiler compartments and the crank pits in the engine-rooms. There are coal bunkers along the side throughout the machinery compartment, and the inner skin is continued on forward and aft as sides to the magazines, &c. Above the armour deck the side bunkers extend to the upper deck; and dwarf bulkheads are introduced between the main transverse bulkheads so as to divide the bunkers into spaces varying from ten to twelve feet long. Before and abaft the machinery spaces there are deck flats from two to three feet above the water-line, the spaces between these and the armour deck forming a raft body, which can be packed with patent fuel, coal, and stores as desired.

On the midship section, Fig. 3, is indicated the level of the coal above the armour deck when the normal supply of 200 tons is carried. Besides the coal on the armour deck, a quantity is stowed in the cross bunkers, so that the ship may be in readiness for steaming at speed. Patent fuel is shown on the slopes of the deck up to the level of the top of the armour deck. Ordinary coal may be carried here, but patent fuel has advantages which are, I think, worth securing, at least to this limited extent, when it is possible to do so. The advantages are these: patent fuel may be stowed so as practically to exclude all water, however much the side may be riddled in action, except in so far as it is blown out or otherwise removed; it is less liable to be blown out than coal by shell fire, and is much less liable to be washed out by the action of the sea through large openings made in the side; and it forms an excellent shovelling flat down to which coal may be removed without risking materially loss of buoyancy and stability in action. With the full supply of coal, the top of the armour deck is 6 inches below the water-line; but part of this full supply may consist of patent fuel or coal in sacks stowed upon the armour deck to a depth of say 2 feet, thus forming a continuation of the raft body forward and aft; and this fuel need not be disturbed until, by the consumption of the coal from elsewhere, the ship is lightened, and the deck armour is raised above the water. If at the deep draught, with the assistance of the cofferdams large volumes of water can be prevented from getting below (which is not likely to be difficult, seeing that any water finding its way to holes in the cofferdams will have but little head), and supposing the armour deck to remain intact, the buoyancy and stability of the ship may be regarded as to a very considerable extent assured even against modern shell fire.

The two sections, Figs. 4 and 5, Plate XXVII, show the belt protection which might have been given to the *Piemonte* without increasing the displacement, Fig. 4 on the supposition that the weight of the patent fuel is put into armour, and consequently the normal supply of fuel reduced by 100 tons, and Fig. 5 on the supposition that 200 tons of coal are carried as at present. The protection afforded in the case of the second is much less than that afforded in the case of the first arrangement, but the ship

provided with the Fig. 5 arrangement would always have as her normal supply of coal the same quantity as the *Piemonte* has for ordinary sea-going purposes in peace time; while the ship provided with the Fig. 4 arrangement would only have as her normal supply the quantity of coal which the *Piemonte* would be free to burn without touching the fuel which might aid her materially in action.

We will compare the protection afforded by the Fig. 4 belt arrangement with that afforded by the arrangement adopted in the *Piemonte*, shown in section on the midship section, Fig. 3. In each of these cases the horizontal deck is of the same thickness, and the width of the belt is the same as the width measured vertically of the sloping side of the *Piemonte's* protective deck. The total thickness of the vertical armour attainable in Fig. 4, supposing the plating behind the armour and an equivalent to the wood backing to be added as armour, is $10\frac{1}{2}$ in. Adding to the *Piemonte's* protective deck, armour of equivalent value to the patent fuel, the thickness of the sloping armour arrived at is 6 in.; this divided by the sine of the slope gives 14 in. as the thickness of the sloping armour, measured horizontally. Thus the advantage is with the sloping armour to the extent of $3\frac{1}{2}$ in. But, besides this advantage in absolute thickness, the sloping armour has a further advantage, since vertical armour is much less effective in resisting projectiles than sloping armour of the same horizontal thickness. The patent fuel also has great advantages over an equivalent thickness of armour in resisting shell fire, and especially shell charged with high explosives, as the resistance takes place over a greater distance, giving the shell time to explode, and the armour has only therefore to resist the broken pieces.

The arrangement with sloping armour has the disadvantage that light shell which would be kept out by the vertical armour will probably blow out some of the brick fuel, and do other damage to the ship's structure; but as the 6-in. quick-firing gun can now penetrate 15 in. of wrought iron, this risk should, I think, be run for the sake of securing the additional protection afforded by the sloping armour. A shell from a 6-in. gun could be fired through the $10\frac{1}{2}$ inches of compound armour, Fig. 4, but it could not, I think, be fired through the side of the *Piemonte* at the water line so as to penetrate the sloping armour, and especially if charged with high explosives. Moreover, against the disadvantage above referred to must be set the fact that the target presented by the comparatively thin horizontal deck, when the ship heels, is very much larger in the case of the ship with vertical armour than in the case of the ship with the sloping armour. The question of cost also is very much in favour of the sloping deck armour. Apart, therefore, from the advantage of being able to carry some 100 tons more coal in peace time, and of having this quantity in reserve to be used in an emergency in war time, the advantage appears clearly on the side of the sloping deck arrangement adopted in the *Piemonte*.

The relative advantages of vertical and sloping armour have been on more than one occasion lengthily discussed by this Institution, but the importance of the question must be my excuse for making the above comparison.

The machinery of the *Piemonte* has been constructed by Messrs. Humphrys, Tennant & Co., Deptford, and consists of two sets of vertical triple expansion engines. Each set has two low-pressure cylinders, and therefore acts on four cranks. The cylinders are of the following dimensions: high-pressure, 36 in.; intermediate, 55 in.; low-pressure, each 60 in., and the stroke is 27 in. Steam is generated in four double-ended boilers, adapted for a working pressure of 155 lbs. Forced draught can be supplied by eight fans, but the stokeholds are arranged so that they can be worked with or without forced draught. Distilling apparatus of ample power has been provided for making fresh water for the boilers; and auxiliary condensers are also fitted in each engine-room.

An auxiliary boiler stands on the protective deck amidships, capable of supplying steam to the auxiliary engines throughout the ship.

The official steam trials of the ship have not yet been made. I had hoped that these would have been completed in time for me to have given the results obtained, but the continuous bad weather on the north-east coast during the last few weeks has prevented their being proceeded with. I hope, however, to be able to add these results to the paper for publication in the Transactions.

At a preliminary trial made on the 28th ultimo some slight defects occurred in connection with the lubrication which necessitated some adjustments. When these defects were overcome towards the close of the day a series of runs were made on the measured mile without the use of the fans, with open stokeholds, and with forced draught. There was very little wind on the occasion, so that much interest does not attach to the steaming without the use of the fans; two runs, however, under these circumstances, showed that the ship could steam about 19½ knots. Four runs made with a moderate pressure of air in the stokeholds, never exceeding a ¼ in. of water, gave a mean speed of 20·168 knots; and with an air pressure of ½ in. of water, the limit fixed by the Admiralty for continuous steaming at sea, a speed of 20·3 knots could with ease be sustained. With closed stokeholds and forced draught a power of 11,600 horses was realised, but the trials under these conditions were not completed. The mean of four runs with forced draught, when about 11,000 indicated horse power were realised, gave a speed of 21·37 knots.

For the official trials the bottom of the ship has been thoroughly cleaned and painted, and some change has been made in the screws, and I have no doubt we shall obtain a very high speed at the trials, which will be made as soon as favourable weather offers.

Whatever speed may ultimately be obtained in this vessel with forced draught, the fact that with natural draught, when the wind is favourable, or with a moderate pressure in the stokeholds, she can steam continuously in fair weather at from 20¼ to 20½ knots, has been fully established. This I regard as of very much greater importance than the high performance which will probably be attained with forced draught. Forced draught with high pressure in the stokeholds—and anything above one and a half inches should, I think, be regarded as high—can only be reckoned upon for a spurt of a few hours, and after such a spurt you will usually find that your boilers require some overhauling.

On Fig. 6, Plate XXVII., are shown the profiles of waves along the side of the vessel, at 20 and 21·5 knots speed,* the drawn line indicating the profile at 20 knots, and the dotted line the profile at 21·5 knots; and I have here some photographs, some of them taken from the foremost upper top, which show that the wave disturbance was remarkably small, and consequently very little work was uselessly wasted in the formation of waves. So small was the wave disturbance when the ship was running at about 21·5 knots, that her high speed could scarcely be realised. This was due also to the entire absence of anything like excessive vibration. The vibration was measured by means of a seismometer, very ingeniously contrived by Mr. A. Mallock, and was shown never to have exceeded ·12 of an inch, horizontally or vertically, while the amplitude of the mean of the vibrations was less than half of this.

With her full coal supply of 600 tons, the vessel will be enabled to steam the considerable distance of 1,950 knots at full speed with natural draught, and she will be able to maintain a cruising speed of 10 to 12 knots for 55 days, during which time she could cover a distance of about 13,500 knots.

As will be seen from the profile, the after deadwood is cut away, and a large balance rudder is provided, immediately in front of which also the deadwood is removed. These features will, I anticipate, give the vessel good manœuvring power, and from the trial already made there is no doubt that this has been secured. I hope to be able to add the results of the turning trials to my paper for publication in the Transactions.

NOTE.—Since reading my paper, the *Piemonte* has had further preliminary speed trials, and her official trials, consisting of a six hours' run with natural draught and a run of an hour and a half with forced draught, were made on the 14th and 17th inst. respectively. At the former the mean speed attained during the run was 20·44 knots, and the mean power developed was 7,100 horses; and during the latter the mean speed exceeded 22 knots, with a mean power of 12,700 horses; the speed maintained over a considerable portion of the run being 22·3 knots, and the power 12,981 horses.

The turning trials which were made on the 17th inst. showed that the vessel could complete a circle of 508 yards diameter in 3 minutes 24 seconds at full speed, and reverse the direction of her course in 1 minute 35 seconds.

* When about 11,600 I.H.P. was being realised,

PARTICULARS OF THE ITALIAN CRUISER "PIEMONTE."

	Ft.	in.
Length on Water-Line	325	0
Breadth, Moulded	38	0
Draught—		
Forward	14	0
Aft	16	0
Mean	15	0
Upper Deck at Side above L.W.L.	8	3
Displacement	2,500 tons.	
Indicated Horse-Power (estimated)—		
With Forced Draught	12,000	
With Open Stokeholds	8,000	
Speed (estimated)	21½ knots.	

Armament—

Six 6-in. Quick-Firing Guns.
Six 4¾-in. ditto
Ten 6-pounder ditto
Six 1-pounder ditto
Four 10-mm. Maxim Guns.
One Torpedo Gun fixed Forward.
Two Torpedo Guns fixed on Broadsides.

Weights—	Tons.
Hull and Fittings	970
Protective Material	280
Equipment	130
Machinery and Spare Gear	720
Coals, normal supply	200
Do. bunkers full	600
Armament	200

Protective Deck—

Thickness on Slopes ... 3 in.
,, ,, Horizontal Parts ... 1 ,,
Conning Tower ... 3 ,,

Particulars of Machinery—

Diameter of Low Pressure Cylinders, each 60 in.
Ditto Intermediate ditto 55 in.
Ditto High Pressure ditto 36 in.
Length of stroke ... 27 in.

Radius of Action—

At Full Speed with Natural Draught, 1,950 knots.
At from 10 to 12 knots ... 13,500 ,,

DISCUSSION.

Sir EDWARD REED, K.C.B., F.R.S., M.P. (Vice-President): My Lord, I should be glad to make one or two remarks upon this paper. If one could venture to use it in the following way, I think it would be a very interesting one indeed, if we could suppose that this ship is attacked by a similar one. I suppose it will be admitted by builders and designers, and everyone who has read this paper, that immediate destruction would be the almost necessary consequence. Because, what are we told? We are told that she is armed with a number of guns which fire with tremendous frequency, and many of which will send their shell through a 15-in. armour plate. She herself is furnished with what is called throughout the paper an armoured deck. I should like the meeting to pay particular attention to the fact that this vessel is furnished with an "armoured deck," and then to consider what the thickness of it is. It is an inch thick.

Mr. P. WATTS: Three inches.

Sir EDWARD REED: No, one inch. The "armoured deck" of the ship is one inch thick amidships, and it slopes down at the sides with a thickness of three inches, to meet the agencies of modern warfare. Well, if a 6-in. gun will go through fifteen inches of armour, what sort of gun will it take to go through these three inches of armour? I should like to know still more what kind of gun will it require to go through the one inch of armour which constitutes the "armoured deck." There is not the smallest doubt in my own mind as to that. I would take the argument one step further, and ask what it would take to go through these cofferdams and water-tight compartments which are erected, and which we are carefully told exist, not only below water, but above water. There are people who profess to think it is an immense advantage to have a number of thin water-tight com-

partments in a battle-ship above water; but what is the conceivable use of them? How are these thin water-tight compartments above water to be of any conceivable use or advantage when the ship is raked, not by guns of a high calibre, but by guns such as she herself carries? What is the use of these cofferdams and these water-tight compartments of such extreme thinness? Of what use are they when a raking shell comes from a gun of the kind which that ship carries, and of which she carries several, and which fire very often? My Lord, I do not want to throw any discredit on the type of vessel. I have not the smallest doubt, if one sat down to consider, he might find many cases in which such a bubble of steel, so formed as to carry this very powerful armament, might conceivably be of use; but if we are told that this bubble of steel, which any one and every one of her own guns would destroy in a moment, or at any rate inflict upon her such injury that destruction would not be long in ensuing—if we are to be told that that is a fighting machine, I can only say that it is wonderfully easier in these days to build fighting machines than I have hitherto regarded it. I have no doubt, my Lord, that in an audience like this it will be quite understood that I am not seeking in these remarks to cast any discredit upon this particular vessel. I am only availing myself of the description of such a vessel to challenge its importance and position in the naval warfare of the future. No doubt it will be a very valuable kind of vessel for snapping up those small merchantmen—those small merchant steamers of this country which my friend Mr. Martell considers it undesirable to arm—and I am bound to say it would dispose of them equally well, probably, if they were armed with a couple of guns; although I must say that if the men who are commanding the ship were to be sent to chase a nine or ten knot merchantman, and she were armed at the stern, I think this vessel might run very considerable risk of having very serious injury inflicted upon her. My Lord, there is one feature that strikes one in looking at the very interesting and valuable photographs which have been shown us, and that is, that the wave—the permanent wave, if one may call it so—at high speed, seems to be located very favourably for the speed, the crest being just over the propellers; but is situated very unfavourably for the protection in view of the exposure which it gives, because the wave falls down very low right abreast the boilers, and that is rather an unsatisfactory position in which to have an unusual amount of exposure. I do not, however, attach very much importance to that circumstance, for the reason that I think it might readily be answered that these ships will not really be expected to fight when they are going at the high speed at which the photographs were taken.

Mr. P. Watts: Yes, certainly they will.

Sir Edward Reed: Well, if that be so—if they are going to fight at 21 knots, the natural wave which the vessel forms at that speed will tend greatly to the exposure of the engines and boilers. Of course it will be replied, my Lord, that in addition to this armoured deck, an inch thick—and I do not know how long a deck an inch thick has been an armoured deck, but I have known inch decks which were not armoured decks, and which were not so described or put forward—it will be said that, in addition to this, there is some coal or patent fuel. Well, I have no doubt that coal, or patent fuel, or anything of the kind will add somewhat, according to the quantity of it, to the resistance which is offered; but I cannot lose this opportunity, my Lord, of protesting against what I regard as the folly and absurdity of putting forward the ship's fuel, which is there for the express purpose of being consumed, as a great feature of her defence. Why, if you cannot use it, you might as well have some other and better defence; and, if you do use it, it is no longer defence. What is the earthly use of talking about a material situated like that as a defensive material? Of course, I quite admit that, while it is there, it is as wise to keep it in that place, as it would be to put your bread and biscuit, or stores of any kind, to help to protect the vessel; but to put it forward as a

substantial part of the defence of a ship, however useful it may be from the point of view of the persuasiveness which you have sometimes to exercise upon purchasers and people who order ships; to put it forward at a meeting of naval constructors and naval officers as constituting any part of that defence which you are entitled to regard as permanent, and to be used in this ship for war purposes, seems to me to be quite wrong. I hope it will not be understood that, in making these remarks, I lose sight of what I do not forget, namely, the very many interesting and valuable features of this design; I think it is quite proper, my Lord, to say that this is a type of ship in which it may well be said that the fire should be made as overwhelming as it can, and, of course, I entirely approve of having a comparatively large number of powerful and quick-firing guns. Quick-firing guns seem to me to be the essential part of the armament of such a ship; for, if she is not extremely quick in disposing of her enemy, she will, in a very little time, be disposed of by him.

Mr. W. H. White, F.R.S. (Vice-President): My Lord, I would like to say a few words, if I may, but I do not conceive that the discussion is really closed. I wish to recall the attention of the meeting to the facts set out in the paper. The question of the place or use of this type of ship in naval warfare is, of course, one upon which great differences of opinion will prevail. But we have here described a vessel of small size, yet of remarkable speed, and of extremely powerful armament, with a good coal supply. She has, in addition to all these features, a deck, which we may call either protective, or armoured, or anything else we prefer. Any adjective may be put before the word deck, but this deck undoubtedly forms a roof over the vitals in the hold, and is proof against many forms of attack, and is, therefore, of no mean value. Now, I think I have summed up as shortly as I can what are the facts of this paper. Splitting hairs about whether this undoubted protection shall be called an armoured deck or a protective deck, does not seem to me to be of very much importance. The important thing is that in this comparatively small ship there has been devoted to the protection of the vitals a very considerable weight of material. And, further, a great many authorities, though not all, conceive this material to be well disposed in the form in which it has been placed. It would ill become me to say a word on the merits of this design. It has been produced as a sequence to a number of ships which I myself had the honour to design and build in the same yard. The meeting will, however, allow me to say that we all thank Mr. Watts for bringing before us such a description of a most important piece of professional work, in the execution of which new problems have been attempted and satisfactorily solved.

The President: Before I call upon Mr. Watts to reply, I want particularly, though I very seldom venture to do such a thing, to ask a question myself. I want him to tell me, or somebody to tell me, how it is intended, or rather how it is proposed, to feed one of these quick-firing guns in such a way as to maintain the efficiency which they are supposed to have in extraordinarily rapid firing. I want to know how the ammunition is to be conveyed fast enough to exercise to the full the rapid firing powers of the gun. I should very much like that question to be answered, because I am accustomed to load guns myself, and I should like to know very much how that is going to be done on board ship in such a way as to maintain the full efficiency of the gun.

Mr. P. Watts (Member of Council): My Lord, with regard to the question you have just put, which is a very important question, I have only to say that the matter has had most careful consideration, but it belongs to "the undivulged" of Elswick.

The President: Then I do not press for an answer.

Mr. P. Watts: With regard to what Sir Edward Reed has said, I do not think if two *Piemontes* were to attack one another both would be immediately destroyed. No doubt if they were equally well

manned, they would knock one another about pretty considerably ; but I do not think they would sink one another very easily. Sir Edward was disposed to remark upon the thinness of the horizontal part of the armour-deck, but the chances of this horizontal part being hit as long as it is horizontal, and even when inclined by moderate angles of heel, are not great, and its resistance even for large angles of heel is considerable. The sloping parts of the armour-deck are more likely to be hit, but these are three inches thick over their whole width. The ship could not be rapidly destroyed by similar guns to her own ; on the contrary, she has a very reasonable chance of escaping destruction when attacked by such guns, especially when the upper side bunkers carry coal or patent fuel, as indicated on the midship section, and I presume this can always be done when it is desired to do so. The 6-inch gun will not penetrate the slopes of the armoured deck, if the shell has first to traverse six or eight feet of patent fuel.

Sir Edward Reed : Not the one that penetrates the 15-in. armour ?

Mr. P. Watts : The 6-in. gun can penetrate 15 in. of wroughtiron, but the resistance of the slopes with the patent fuel upon them against horizontal fire is equal to the resistance of at least 14 in. of steel. The resistance of the fuel is equal in value to at least that of 3 in. of steel. Thus we have the equivalent to about 6 in. of steel armour on the slopes, and if you measure the 6 in. horizontally you have upwards of 14 in., besides which you have the resistance to the progress of the shell extending over some 8 ft., during which time it will certainly be exploded, and the armoured deck will only have to withstand the broken pieces of the shell. Sir Edward referred to the possible effect of raking shot. It is quite possible to conceive the vessel to be pitching, and to receive a shot which might prove fatal to her. As we say, " A chance shot may kill the devil ; " but there is some provision in the ship against raking shot. The chain lockers are placed above the armoured deck, and extend right across the ship, the cables, &c., forming a sort of armoured bulkhead forward protecting the ship against raking fire. It would, of course, be very easy for projectiles to penetrate the water-tight compartments above the armoured deck, especially when there is no coal in them, and this is why a very large number of compartments have been constructed. A number of them might be flooded without endangering the ship, even when all the coal has gone. With the coal or patent fuel in these spaces a small quantity of water would find its way in, but the ship would be very little the worse for this. Below the armour deck the ship cannot in the ordinary way be attacked by shot and shell, but the careful subdivision is intended to provide against attack mainly by the torpedo and the ram. Neither, of course, will the thin sides of the cofferdams offer much resistance to projectiles, but the cofferdams can be packed with material which will offer resistance, and in the event of their being perforated, the structures will afford facilities for stopping the leaks even while the action proceeds. With regard to the exposure of the side by speed, as may be seen by Fig. 6, the hollow amidships does to a considerable extent expose the side, but it must be remembered that this is only in the immediate vicinity of the ship. Some short distance out from the ship you have the diverging waves, which are considerably above the level of still water, and the ship herself is probably lower with reference to this level than when at rest. I believe these facts have to some extent been lost sight of. I do not think the exposure is in reality nearly as great as is commonly supposed, especially when the ship is fired at from some distance. Sir Edward appeared to object to much credit being taken on account of the presence of the coal or patent fuel. You must carry coal, and it is an advantage to get as much protection out of it as you can while it is on board. I do not claim that the protection thus obtained should be regarded as permanent, but the fuel which gives protection can always be retained to the last. Of course, if the fuel were all consumed it could no longer give protection to the buoyancy and stability, but if it should be desirable under any circumstances to retain the

portion which gives protection, it could always be retained by carrying sufficient additional coal. The ship can steam at 20 knots with natural draught with 600 tons of coal on board, and in that condition she has when patent fuel is carried and stowed as described, a solid raft body, such as that described by Sir Nathaniel Barnaby, along her whole length, 2 ft. above the water line along the middle of the deck, and 5 to 6 ft. above it at the sides, and no amount of penetration of the side of the ship would endanger her. Whereas if the fuel were put below the armour deck the protection of the ship would be decreased instead of increased, for the volume of the spaces in the vicinity of the water line into which water could flow as the result of the ship being perforated along the side would be much increased, instead of being very much decreased. On the whole I venture to think the *Piemonte* is a very substantial sort of bubble. She is protected against war risks in a manner which a large proportion of those entitled to speak with authority on the subject, pronounce—at least for this class of vessel—the best possible. The power of her armament is exceedingly great compared with that possessed by any similar vessel, and she is possessed of very much greater speed than has been attained by any other war vessel afloat.

The PRESIDENT: I assume you wish me to thank Mr. Watts for his paper and the discussion which has ensued thereon. A peculiar interest attaches to his paper, as this is the most important ship which our friend has designed in his high position at Elswick; it is therefore particularly acceptable.

WATER-TUBE BOILERS FOR WAR-SHIPS.

By J. I. Thornycroft, Esq., Vice-President.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 11th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

In modern war-ships the weight to be carried is an ever increasing source of difficulty. The essence of a skilful design is the combination of great powers of offence and of defence, of speed and coal endurance, in a limited displacement. In the ironclad of to-day, evidence may be seen in every part of the struggle of the designer to reduce the weight of his elements without impairing the efficiency of the structure as a whole. Forced to increase the thickness of his armour, he covers with it only a small portion of the hull, and he hardens the face of his plates to increase the resisting power of a given weight of material. The structure of the hull has been elaborated until the amount of material has been reduced to a minimum consistent with safety. The weight of the guns has been reduced, I am inclined to think, quite as much as is desirable when the amount of the charge is considered; and the engines, like the guns, have had their pressures and velocities increased until progress in these directions appears to have reached a limit. In the boilers, however, there is still much room for reduction of weight, not only by economising material but also by economising fuel. Mr. Sennett's paper, last year, shows how strong is the pressure brought to bear upon the engineering department with a view of saving weight in the boilers. His answer has been, reduced test pressures and reduced thickness of material. Economy of fuel in steam boilers depends greatly on the amount of heating surface that can be allowed for a given evaporation. If we can estimate the weight of a unit of heating surface in different classes of boilers, it becomes a very simple matter to calculate the comparative weight of the boilers for a given economy of fuel. On the other hand, for a given weight of boiler we can estimate the saving in fuel, or the increase of power, due to a change from one class to the other.

Some experiments were made at Portsmouth two years ago having a direct bearing on this subject. By an evaporative trial, at natural draught, of two boilers, the one locomotive and the other water-tube, the heating surfaces of which were in the ratio of 1 to 2·3, it was found that in the case of the latter boiler the rate of evaporation could

be increased in the ratio of 1 to 2·36 with the same economy. It follows that a water-tube boiler will evaporate a little more water per foot of surface than a locomotive when working equally economically, and therefore, under these conditions, the weights of the two types will be proportioned to one another as the weights of a unit of heating surface. The weights of boiler and water and fittings per foot of heating surface of the locomotive and water-tube boilers tried at Portsmouth were 25·6 lbs. and 9·61 lbs. respectively. The weight, therefore, of a water-tube boiler and water, working at the same economical rate as a locomotive boiler and water, will be less than half. In practice we prefer to make a smaller reduction in weight, and to work the boilers less hard by giving a larger allowance of heating surface for a given quantity of water to be evaporated. By this means better economy is obtained, and much less stress is put upon the boilers.

Whereas the common wind pressure for locomotive boilers in torpedo boats is from 4 to 5 inches of water, we do not usually exceed 1½ to 2 inches with the water-tube, and a corresponding reduction could doubtless be made in war-ship practice. The following figures will show the amount of the saving in weight :—

	IHP
Indicated horse power per ton weight of water-tube boiler, including all fittings, mountings, water, pipes, donkey, spare gear and funnel	68
Locomotive boiler of same power in a torpedo boat	48
Locomotive boiler in latest English torpedo catcher	43
Boilers of H.M.S. *Anson*	21·3
Boilers of P. &. O. steamers...	16·6

This boiler has other qualities which render it particularly suitable for war-ships. In addition to the saving in fuel due to the greater economy, the power of getting up steam in a short interval of time must tend to further saving, for when it takes a long time to raise steam it must be kept up continuously, if there is a possibility that it may be wanted with only a notice of an hour or two. With the power to get up steam quickly, it would be sufficient to keep steam in one boiler, for the purpose of starting auxiliary engines and warming the main engines. It has been found that steam can be raised in from 15 to 20 minutes without risk of injury, and forced firing has never caused leakage of the tubes.

The water-tube boiler is shown on Plate XXVIII., and is further illustrated by the model on the table. It will be seen to consist simply of three cylinders lying parallel to each other, the two smaller being at the base of the structure, and the larger one at the top. These cylinders are connected by means of two large tubes at the fire-door end, and are stayed at the opposite end by a triangular frame. A further connection exists between the top and bottom cylinders in a great multitude of small tubes. These are the steam-generating tubes. On looking carefully, it will be noticed that the inner row of tubes, forming what would be the crown of the fire-box, and the outer row,

forming what would be the shell in an ordinary boiler, are, by means of a very simple alteration of their ends, made to lie quite close together, so that none of the products of combustion can pass between them. The lower part of the upper cylinder is thus protected from the direct action of the heat. The tubes are fixed in the cylinders by expanding in the ordinary way, and an outer casing of thin steel covers the whole. In the upper half of the upper cylinder a curved baffle-plate with serrated edges is fixed to protect the steam pipe, and effect the separation of the water and steam. The fire-bars are disposed at the base of the boiler, and between the two lower cylinders. They are surrounded by fire-brick slabs, which act as protectors to the lower cylinders, and as bridges over which the flame must pass on its way to the chimney.

When steam is required the boiler is filled with water up to nearly the middle of the upper cylinder, and the fire is lighted. The products of combustion pass over the side bridges and through the spaces between the lower ends of the generating tubes, into the spaces between the tubes, and along them to the upper half of the upper cylinder, whence they pass to the funnel. In addition to the heat absorbed from the gases a great amount of radiated heat is received by the tubes forming the crown of the furnace. The heat absorbed by the tubes is at first only communicated to the small volume of water within them, so that the density of the water is rapidly reduced. At the same time the two large tubes which connect the upper and lower cylinders are filled with water of the original density, thus more than balancing the weight of the contents of the generating tubes, and causing rapid circulation. The discharge from the tubes into the upper cylinder is a mixture of steam and water, and these elements are separated as they flow over a curved baffle-plate, which is placed immediately under the openings of the tubes, and encloses a considerable space above the water surface protected from spray, and from which the steam is taken.

The absence of leakage may be briefly explained as being due to the facts that the tubes can expand freely, and that their connections with the upper and lower cylinders are not exposed to the heat of the fire, while in fire-tube boilers the part of the tube exposed to the most severe heat is its junction with the tube-plate, around which there is no water to cool it.

Opinions have been expressed that this boiler will have but a short life. Opinions on such a matter are not of much value, and the author thinks it will be of interest to the Institution to learn how the boilers of this type, which are already at work, have stood the test of time. The first one was made for the Congo Mission steamer *Peace*. The vessel was tried on the Thames in 1882, then taken to pieces, the boiler included, and re-erected in Africa by the Rev. George Grenfell, with black assistants only. She commenced work on the Congo in the spring of 1884, and has performed continual service since. The last news we had of her was contained in a letter from Mr. Grenfell dated the 18th of September last. He says: "The boiler itself is doing splendidly,

and we have no difficulty in keeping up steam sufficient for 400 revolutions; in fact, quite steam enough for any purpose, and when head to wind often too much."

The next boiler was fitted in a second-class torpedo boat for the British Navy, and tried early in 1866. It has therefore been at work for about three years. I obtained permission from the Admiralty to remove some of the small tubes for the purpose of ascertaining their condition. These specimens were cut out last week, and are exactly in the condition in which they were taken from the boiler. In examining them I was exceedingly pleased to find that the deposit in them was so very small in amount. It appeared possible that this boiler might fail, from the tubes becoming obstructed by deposit, and as it is impossible to gain access to much of their interior, this would have been a very serious drawback. I am not aware that the boiler from which these tubes are taken has been treated with any special care; the surface condenser is of the ordinary kind, and is not specially made to prevent leakage.

A few of these tubes, however, are not in such good condition as I had hoped; oxidation seems to have taken place to a slight extent within them, and the external surface of those taken from the outer rows has been very much rusted, and seems to indicate that these tubes have been wet for a considerable period. This is corroborated by the fact that the plates forming the external casing are also decayed in places. It is most satisfactory, however, to find that the tubes in the flue, and also those forming the fire-box, are in most excellent condition. The blue scale is still visible on the outside, and the parts of the tubes exposed to the most intense heat do not show the least trace of injury from the fire.

The next examples are the boilers of the *Ariete* and *Rayo*. It will be remembered that an exceedingly high speed was attained in these vessels, due largely to the lightness and steaming power of the boilers, of which each boat had two. They were delivered to the Spanish Government in August, 1887. Very soon afterwards newspaper reports appeared as to defects having manifested themselves, and it was stated that the boilers were condemned, and were to be replaced by others of locomotive type. We had no communication made to us officially concerning these alleged defects.

Seeing in the newspapers an account of certain manœuvres in which these and other torpedo boats were engaged, where it was stated that one of the boilers of the *Ariete* was disabled, we applied to the Minister of Marine for permission to send an engineer over to examine the boilers, and to put right any defects which had arisen. After much delay this was granted, and our engineer reports as follows :—

"The work of removing pipes, casing, &c., was commenced March 15th. On removing the front and back plates of boiler casing, all the small tubes were found covered with a coating of soot from $\frac{1}{8}$ in. to $\frac{3}{16}$ in. thick. I then caused the side casing

to be removed; when this was done the lower parts of the casing (adjoining the coal bunkers) were found wasted away, caused by small coal, ashes, and soot being allowed to accumulate to a depth of about 5 in., the steam cleaning gear pipes being imbedded and partially destroyed.

"The front frame plate carrying the ash-pan doors was then removed, and I found the ash-pans firmly fixed in a bedding of small coal and soot which had been allowed to accumulate; this had to be dug away before the ash-pans could be removed, and through this accumulation it has to some extent corroded the sides of ash-pans. On going inside the fire-box I found the fire-bricks much damaged, and they have been in this condition for some time; those on the port side will have to be removed. The centre fire-brick on the inside of end-casing nearest the safety valve end of boiler is missing, and from the crumpled appearance of the plate, has been in this state for some time. The inside of separator tube and collector tubes are very fair, no appearance of pitting being discernible, although the collector tubes have a deposit on the bottom of $\frac{3}{8}$ in. of lime, &c. The separator dash-plates (zinc) have wasted in their thickness from $\frac{1}{8}$ in. to $\frac{3}{16}$ in. on the part that has been in the water, while the upper parts have a great deal of sediment fixed on them. The zinc bars in the collector tubes are but slightly worn.

"I have examined the safety valves and stop valves, and these are in a very fair condition. This day I have tried the small tubes with water, and have discovered one tube in the row marked I, or the second row counting from the top centre of separator, and it is the eleventh from the safety valve end of boiler; this is the only one I have discovered, and it is caused through a small hole in tube of about $\frac{1}{4}$ in. in diameter. I propose to draw this tube and refit a new one, to remove all sediment from the collector tubes, clean zinc dash-plates and bars, refit new firebricks, well cleanse the outside of small tubes from the soot, and remove the damaged parts of side casings and fit strips of plate 8 in. deep to take the place of damaged parts.

I would add that there is nothing in these repairs, excepting the damaged tube, but what could have and should have been done by the stokers belonging to the ship, but which, from the total neglect the boiler has received, has very seriously impaired the efficiency of the boiler, until the neglect is rectified. In reference to the damaged tube, there are a number of special plugs supplied with the boat for the purpose of putting out of use any defective tube or tubes. Had this been applied—and the application of it is very simple—no annoyance would have been experienced, except instead of 918 tubes there would have been 917. From the general appearance of the boiler and fittings, it shows it has been greatly neglected, for in addition to the steam cleaning gear, there are brushes supplied to assist; these have not been used, nor have the end plates been removed for this purpose nor for inspection, since the boat left England."

The next vessels in order were the Danish torpedo boats *Stören* and *Solöven*, delivered in 1887. Since then we have supplied water-tube boilers in all the new torpedo boats built for that Government, and are now replacing the locomotive boiler in a boat 5½ years old, with two water-tube boilers.

Careful experiments have recently been made by Professor Kennedy on one of these boilers, in order to ascertain the evaporative efficiency at different rates of working. The best result was with natural draught, when the evaporative duty reached 13·4 lbs. of water per pound of coal, from and at 212°. The calorific value of the coal, as determined by analysis, was 15·41 lbs. per pound of coal. The efficiency of the boiler with natural draught was therefore 87 per cent. of the theoretical evaporation, which we have reason to believe is the highest on record.

DISCUSSION.

Mr. W. Parker (Member of Council): My Lord and gentlemen, I feel sure that all marine engineers will feel deeply indebted to Mr. Thornycroft for reading this paper and giving us the result of his work so far as it has gone. It is very well known that a great amount of saving in weight can be obtained by having a boiler built upon the water tube, or as I term it, the cellular principle, in opposition to the tank principle. Steam can no doubt be raised more rapidly in a boiler of that description. But the question arises, "Will it last?" I think Mr. Thornycroft has in one paragraph here asked that question. Well, I myself, some years ago, had some experience of water-tube boilers at sea; not in torpedo boats, nor in steam launches, nor in the little vessels in the African rivers, but in ocean-going steamers, averaging from 1,000 to 4,000 H.P. And I may say, in passing, that the reason the triple expansion engine was not introduced some ten years before it was, was simply because a boiler, of the description described in this paper, failed at sea. I have brought with me a model of the boiler I refer to, so that your Lordship and the members may see how similar it is to the boiler represented in Mr. Thornycroft's paper. This boiler was called Rowan's boiler, but you will understand that, instead of the tubes ending here, they were continued the whole way across the chambers. [*Describes the model.*] But I do not think I can describe this boiler in better language than Mr. Thornycroft describes his own.

Mr. J. I. Thornycroft: Will you kindly give us the size of the tubes?

Mr. W. Parker: Two inches internal diameter. The water-tube boiler, as shown by the model, consists simply of seven cylinders lying parallel to each other, the three smaller ones being at the base of the structure and the larger ones at the top. These cylinders are connected by means of two large tubes at the back end, and are stayed at the opposite end by frames, and further connection exists between the top and bottom cylinders in a great multitude of small tubes. Now, my Lord and gentlemen, that boiler was fitted in the S.S. *Propontis*, in 1874, and the vessel steamed to Constantinople and back again without any very great accident taking place, and also gave very good results as far as evaporating power was concerned and economy of fuel; but on the following voyage, owing to a slight engineering mistake in connecting these two chambers or sections, the pressures in the two sections could not be equalised, and when one fire was being forced, and the other lying in a quieter state, the water ran through the back tubes from one section to the other, and

the consequence was that one became void of water and exploded with fatal results to several on board. The boiler was afterwards worked for another year and a half, and at the end of that time it was found that nearly the whole of the tubes at the bottom ends were corroded, and in some cases pitted completely through. I took the trouble at that time to cut out one of these tubes, and it is here for Mr. Thornycroft's inspection. Further than that, these tube ends could not be stopped or plugged; so that if one tube gave way through being in that pitted condition, the whole boiler became useless. I should therefore like to ask Mr. Thornycroft what precautions he has taken to prevent pitting taking place, and what provisions he has made to plug the tubes which may give way in the manner described, and also what provisions he has made to replace them. Now, that was the experience I had in the *Propontis:* the boiler was eventually taken out and an ordinary boiler fitted. As I said before, the failure of this boiler kept back that great introduction of Dr. Kirk's for nearly ten years. Previous to that, in 1870, at Sunderland, and also in 1871, two steamers were fitted with water-tube boilers, but instead of the tubes being vertical, as these are, they were horizontal. One vessel was called the *Fairy Dell*, and the other the *Marc Antony*. The *Marc Antony* was one of the first steamers that sailed between this place and the Cape, for Donald Currie & Co. The record of the *Fairy Dell* was this. She made ten or eleven voyages across the North Sea; the boilers gave trouble every voyage, but on the last voyage they gave out, the vessel fell off into the trough of the sea, foundered, and I think only two persons were saved. The *Marc Antony* took months to go out to the Cape, owing to these boilers giving way, and it was almost twelve months before she returned. After that, the boiler was altered in order to cause the circulation to be more efficient, and to allow of more equal expansion and contraction, and she sailed, I think, for another eighteen months, but on one of her voyages, I think in the Bay of Biscay, the boilers entirely gave out, the vessel fell off, the water got into the ship, and she foundered, but luckily no lives were lost. In addition to these cases there were two very large ships built of 4,000 H.P., two of the largest vessels that were built at that time for the Merchant service. I refer to the *Montana* and the *Dakota*, which were built at Jarrow for the Guion Line. Those vessels were also fitted with water-tube boilers, which gave on a short trial very similar results to those that Mr. Thornycroft has given us to-day. The evaporative power was greater, the boilers were easily steamed, and that appeared to be the boiler of the future. They were working at 150 lbs. pressure; but neither vessel ever made a voyage with those boilers; even the trials at sea, under the conditions of ocean steaming of six or seven days' duration, proved that the circulation in the lower tubes was so defective that it only became a question of time for them to burn, crack, and become disabled, and every one of them failed. Now, gentlemen, I do not wish to disparage this type of boiler in any way, or to say one word against it, but I think it right, seeing that I have had this experience, to state it to you frankly, and I also say that if marine engineers can produce a water-tube boiler which will take the place of the tank boiler under all the conditions which it may be subjected to, they will be conferring a very great boon on the shipowning community. I have always found in ocean steaming, which is entirely different from torpedo work, that the boiler that can be made most accessible and most easy of repair is the most durable boiler. Again, there is one thing I should like to say with reference to a paragraph in Mr. Thornycroft's paper. He says opinions have been expressed that this boiler will have but a short life. Opinions on such a matter are not of much value, and the author thinks it will be of interest to the Institution to learn how the boilers of this type, which are already at work, have stood the test of time. I would like to draw a distinction between a boiler of this type working in a small boat where it can be seen and attended to easily, and one that has to steam for forty days. With regard to tubes giving trouble, I should like to state that boilers of the present day, with the fire inside the tubes, not outside, have been running for eight years without a tube being caulked. Further than that, I saw some boilers of the ordinary

type in Liverpool last week, which have been in existence eighteen years, and are still in very good condition, doing their work well.

Mr. Josiah McGregor (Member): I would like to make a few remarks with reference to Mr. Thornycroft's boiler, but, before doing so, would correct Mr. Parker in calling the model just put on the table Mr. Rowan's boiler. I believe the correct name for it is Rowan and Haughton's boiler, and differs from any of the numerous designs of boilers of this class that Mr. Rowan brought forward at a comparatively early period. I have had to supervise the working of a number of boilers of this description, and for a much longer period than Mr. Parker represents. Some of them were working for four or five years in large paddle steamers, and from my experience of them I must say I am favourably disposed towards the principle of this class of boiler for high pressures and high rates of combustion. We obtained fairly good results from those sent to India, although I don't think they were either proportioned or worked in the most advantageous manner. There were also a number of difficulties met with which experience alone could adequately overcome. One of these, that of the tubes burning or pitting, has already been alluded to. We found that when a tube began to leak it spoiled the whole boiler, and there was no means whatever of plugging it up until the boiler was blown down and the doors taken off. The very slightest leak soon affected the boiler, as it caused an accumulation of hardened soot among the tubes that quite blocked the passages between them and was difficult to remove, while renewing a tube in some positions was found a matter of great difficulty. We had also considerable trouble with the fire bricks and baffle divisions, although latterly these were nearly overcome. Mr. Thornycroft appears to have introduced some kind of steam blower for keeping the tubes clean behind, but, unless used with great care, I fear this may be the cause of trouble, as any dampness on the outside of the tubes tends to clog the soot and fill up the interstices between the tubes, which is a matter of difficulty to remove. The principal difference between Mr. Thornycroft's boiler and those of Messrs. Rowan and Haughton that have come under my notice consists in the introduction of the tubes into the top half of the upper cylinder instead of the bottom half, which I think is an improvement in favour of Mr. Thornycroft's arrangement. I think there is a good deal to be said in favour of this class of boiler for certain kinds of work, and when it receives adequate attention all difficulties and objections to it will be found quite surmountable.

Mr. J. Scott, C.B. (Member of Council): My Lord, I do not know that I should have troubled the meeting with any remarks upon Mr. Thornycroft's interesting paper unless the early paragraphs had formed an argument for the introduction of this class of boiler into ships of the Royal Navy of a larger size than torpedo boats. I certainly join in the remark which has fallen from Mr. Parker as to the strong family likeness which exists between Mr. Thornycroft's model on my left and the model which Mr. Parker has placed in the centre of the table. I believe I have made more of this class of boiler than any other engineer in the country. Thirty years ago I tried to bring this system into vogue. I gave it a very large amount of attention, and I spent a very large amount of time over it, and a very large amount of money; and I regret to say my efforts were entirely unsuccessful, and I will endeavour to tell you as shortly as possible how that came about. The idea of introducing water-tube boilers for naval purposes is a very old one, and dates from the year 1860. In that year I had the honour of laying before he Admiralty of that period a scheme very like the boiler which is here, and very strongly resembling that of Mr. Thornycroft; and at the same time I laid it before the French Admiralty. Monsieur Dupuy de Lome, who was at the head at that time of the French naval affairs, was so much struck with the advantages arising from the lightening of weight, as pointed out by Mr. Thornycroft, that he gave me an order not only to build a boiler, but a compound engine—the

first compound engine of the French Navy—fitted with a boiler of this type, but he also gave me an order to build a ship to hold them, so that I was able to carry out the whole of my experiments in my works in Scotland. I built a despatch vessel of about 650 tons displacement, and fitted it with compound engines of 140 lbs. pressure in 1860. Very shortly after that, my firm being at the moment engaged in engining four small corvettes building at Woolwich and at Deptford at that time, I pressed the engineering department of the Board of Admiralty to allow me to fit one of these vessels with engines similar to those which were being fitted to the French corvette. The alteration was sanctioned by the Admiralty, but with the proviso that the top of the boilers must be 1 ft. under the water-line, as was then, I think, the rule. It was found impossible with that type of boiler—which, as you will observe, is necessarily high—to carry out that regulation, and I was obliged to abandon the order, and revert to the original system of boiler in use in 1861. Further than that, many merchant ships, some of them destined for river service in India, as has been mentioned by one of the gentlemen who preceded me, were built by my firm, and also several merchant ships of considerable size for sea-going purposes. The results set forth in the end of this paper as to the evaporative powers of this boiler are, I believe, perfectly correctly stated. I cannot remember the decimal points at this moment, but if any of you will take the trouble to refer to the edition of Professor Rankine's work on steam engines, published about the year 1883, he will find an account of an experiment there showing the evaporative power of the boilers made at that period to be as nearly as possible what Mr. Thornycroft says are the best results obtained, and I agree with him that that result can be obtained from boilers of this type. At the same time, I agree with what has fallen from Mr. Parker, that what may be an excellent boiler, or system of boilers, for a torpedo boat may prove to be an extremely bad boiler for vessels of larger size. One feature in the construction of this type of boiler is the number of rows of tubes which need to be inserted in the tube plate, which necessitates the cutting away of almost the entire surface of the plate, and although we now possess the advantage of steel, it has always appeared to me that the form of the tube recipients, although they are in some parts thickened very much, is a dangerous form. But apart from that, as has been pointed out by Mr. Parker, there is a most extraordinary tendency on the part of boilers of this class to develop pitting, and I find that even the successful torpedo boilers described by Mr. Thornycroft are subject to this little complaint, because on page 275 I find that the engineer of his Spanish torpedo boat found "one little hole." This does not at all surprise me, gentlemen. I used to find a great number of little holes from time to time, and in one of Mr. Parker's models I see a hole, with the form of which I am perfectly familiar. These holes used to develop in a most extraordinary way. I once saw the case of a merchant ship of about 800 tons, which I engined and fitted with boilers of this description, with her cargo on board at the quay, when one of these holes suddenly developed itself, and a rush of steam took place to such an extent that it drove every man out of the engine-room until the whole of the water in the boiler was evaporated, and this shows the danger that may arise even from minute perforations of that kind. It is evident that if there is a hole of this kind in any part, you cannot get at it, and it is impossible to stop it in any way without letting the water out of the boiler. I think that is one of the risks and one of the dangers which any naval adviser would have regard to before recommending a boiler of this kind. Well, then, as to the exterior corrosion that takes place, if you use the steam blower which I tried you will find it is frequently difficult to remove the soot which is necessarily deposited there, even, I should fancy, with the advantage of forced draught, especially if North country coal was used, and the mixture of the steam which is used to drive the soot off forms a very corrosive element, which I have not the least doubt accounts for the state of the tube taken from the outer row, which Mr. Thornycroft was good enough to hand round the room just now. I am also perfectly familiar with that phase of the arrangement which comes from the deposit of the soot in

that way. I have not the least doubt that this class of boiler will be found extremely valuable for torpedo boats, which, neck or nothing, must be able to go for a few hours, but I certainly deprecate the idea of attempting to introduce it either into a merchant ship or into a naval ship in connection with engines of any power and size.

Mr. G. W. Manuel (Member): My Lord and gentlemen, certain comparisons having been made by Mr. Thornycroft in his paper regarding the indicated horse power obtained from a boiler similar to that shown on the drawing before us for every ton of its weight, against that obtained in boilers of the mercantile marine and mail service, such as in the Peninsular and Oriental Company's, must be my excuse for the few remarks I would make on this boiler. It was stated that as much as 68 I.H.P. were obtained per ton weight, and in the locomotive type generally used in torpedo boats 48 I.H.P. were obtained, whilst in H.M.S. *Anson* 21·3 I.H.P., and, finally, the boilers in the P. and O. Company's gave only 16·6 I.H.P. The latter estimate is correct for ordinary sea work with natural draught on long sea voyages; the former are due to short trials and forced draught on the boiler in question. I wish to point out, in reference to the above figures, that it is hardly fair to make a comparison of boilers for torpedo vessels, when every effort is made to secure lightness of machinery and large power, with boilers in the mail service, where lightness is wisely sacrificed to the more valuable qualities of safety and endurance. No doubt this is a boiler possessing large evaporative power with forced draught, and for the class of vessels for which it was designed, such as torpedo boats, where quick and short action and light weight are required, it is an improvement above the locomotive type. It will be remembered that in the last autumn manœuvres a number of the boilers gave out in this class of vessels of the latter type, owing to the flat surfaces, such as tube plates, &c., being unable to stand the fierce flames to which they were exposed, and in some cases the fire-box crown plate came down, and in others the stays gave out with serious consequences, besides disabling the vessels. The Thornycroft boiler seems to me to have been designed to avoid such mishaps, as none of the tube plates are exposed to the direct impact of flame and there are no stays, though I differ in regard to its suitability for the work of the merchant service. However, if such a boiler could be used it would get over many objections now existing; vessels would be able to carry more cargo, and there would be economy in fuel, the heat from combustion being absorbed in the boiler by the large heating surface and free circulation. But the question is, as Mr. Parker put it, one of duration. How long would this boiler steam at full power developing this 68 I.H.P. per ton weight? And can we put a boiler like this in a mail steamer steaming continuously—except, say, two short stoppages for coal—12,000 knots? I think, gentlemen, I would not care to make the experiment. Considerable trouble would arise by the choking up the air and smoke spaces between the tubes, more especially the lower parts, with dust and ashes. During continuous steaming loss of draught efficiency would be the consequence, and damage to the tubes in endeavours to clear same, causing slight leakage, which would make matters worse. Then the complete disablement of the boiler would result if one of the four hundred tubes gave out, which means blowing out the boiler water, waiting until the boiler cools if time permits, plugging up the tube, or fitting a new one, along with the usual risks attending such an operation of leakage amongst other tubes, this operation having to be often done in haste. Troubles would arise from the deposit of scale, &c., in the inside of the tubes on long voyages; for, although I have no doubt the intention is to make up losses by distilled water, it is well known that losses have to be made up quickly when water gets low, and sea water to a certain extent will be used. In a large steamer this would be considerable, and, in my opinion, this boiler would not work satisfactorily for many days at full power. I wish, however, to state that in this country we are behind in the matter of marine tubular boilers, for in France the Company of the Messageries Maritimes had the Belleville

tubular boiler in use in some of their steamers for the last two years, and I understand, except requiring to be supplied with distilled water, did not give much trouble on long voyages.* Another French company, the Fraissinet Company, had adopted Messrs. D'Allast's tubular boiler, supposed to be an improvement on the Belleville, the circulation being more rapid. This Company had expressed themselves satisfied with the venture, and it had been in use for five years. At the same time the economy of fuel as compared with the ordinary marine boiler was doubtful—an important consideration as regards weight and space.

Mr. J. List (Member): My Lord and gentlemen, I wish to offer a few remarks on this paper, as I have had the pleasure of making a short run in one of Mr. Thornycroft's torpedo boats, in which these boilers were fitted. On that occasion there was no difficulty in working the boilers. They steamed very freely, and there was an entire absence of priming, though they were brought rapidly up to their maximum power, and worked under strong forced draught, while, to judge from the appearance of the water in the gauge glass, the circulation in the boiler was quite steady. The objections to a boiler of this type for ordinary sea-going work are these:—(1) The risk of perforation of the tubes, due to "pitting." (2) The risk of these comparatively small tubes becoming choked with scale and burned. (3) The difficulty of keeping the oil used for the internal lubrications of the engines out of the boiler. (4) The risk of the boiler being damaged by external corrosion, from the lodgment of damp soot or dust among the tubes when not under steam. Taking these objections in order, it appears to me that the first, viz., the risk of "pitting," is the most serious. If sufficient surface of metallic zinc can be introduced below the water-line in the upper receiver and in the two lower receivers, to protect the relatively great wetted surface of the tubes, and also the interior surface of the receivers, then "pitting" can be prevented; but, failing the possibility of applying sufficient zinc surface in a practicable form, then I fear constant trouble would result from the frequent perforation of the tubes. The second difficulty, viz, that due to scale, is not so serious, as now it is the general practice to make up the waste with distilled water, and double and even triple effect distillers are coming into use for this purpose. There still remains, however, the risk of the surface condenser leaking, or of a greater waste taking place (perhaps from leakage of the boiler itself) than the distilling apparatus is able to cope with. In this way considerable risk might be run with such a boiler as this on a long voyage. The third, or internal oil difficulty, is one that I am not aware has been met at all yet. Hydrocarbon oil must be used for lubricating the internal working surfaces of the engines, and also for the piston rods and valve spindles; a certain percentage of this finds its way through the condenser into the boilers, and in the ordinary type of marine boiler this oily deposit on the tubes and plates has to be periodically scraped off. Whether this deposit would lodge in the tubes of Mr. Thornycroft's boiler, and give trouble after some length of time, I am not prepared to say. Possibly the circulation may be so good as to prevent any such deposit in the tubes, but it might be found in the bottom of the upper receiver, and would possibly lead to overheating there. These are points which only lengthened experience with the boiler will settle. With regard to the fourth objection, viz., the risk of external corrosion, due to the accumulation of dirt amongst the tubes, that is one which I feel sure can be obviated by care and attention on the part of

* This boiler of Mr. Thornycroft reminds me of the book written by Jules Verne, "A Thousand Leagues under the Sea," which we are fast approaching, except that all power was produced from the sea, but how was not explained. Engineers having to take charge, and work boilers and machinery of this type, do this with their lives in their hands, and require to be men of quick resource and great courage—first-class mechanicians—to grapple with contingencies sure to arise. Happily for the Government we have these men, and the Navy is indebted to Mr. Thornycroft and his colleagues for the amount of thought and time they have exercised towards accomplishing the object they have in view.

those in charge of the boilers. Having now pointed out what appear to me to be the difficulties, I must say that this boiler comes much nearer complete success than anything of the kind which has been tried before; and, though I should certainly hesitate to apply it to an ocean-going steamer, with the limited experience yet to hand regarding it, still I think we should all watch closely its development, and I trust Mr. Thornycroft will be able to show us by and by that this boiler is not only suited for obtaining the maximum speed in torpedo boats, but that it is also suitable for use in war-ships and merchant steamers generally.

Mr. J. I. Thornycroft (Vice-President): I have to thank the meeting for doing what I think it is best they should do in this matter—they have endeavoured to show where I am wrong. Now, that is exactly what I wanted to know. Mr. Parker has brought forward a model, and he says that this model represents a boiler so similar to the one I bring before you, that therefore my boiler ought to be subject to the same failure. Well, that I must deny to begin with; I say it is not so similar as to make the same causes operate except one, and that is pitting; and in that respect I am not quite sure it is quite so susceptible; but while I am speaking of pitting I might say this, that pitting when surface condensers were first used was so great an enemy to the boilers, that some people seemed to think that surface condensers would have to be given up again. But pitting is really a chemical question, and since the introduction of zinc in boilers pitting has been greatly reduced. I believe the authorities in France use some precautions in examining the water in their boilers which are not observed here. I believe it is tested with litmus paper to see that it does not become acid. I do not know whether that is done in this country at all, but as we are dealing with the chemical question I may say that it seems to me to be a most proper thing. One of the gentlemen who have spoken points out that the tubes in the boiler I have brought here indicate pitting. Well, that is so, there is some slight indication of pitting in those tubes, but the hole in one of the tubes is, I think, not due to pitting. I think it is some original defect, because the pitting marks that are in the tubes are so exceedingly shallow that where the tubes are cut in two you cannot see in the section of the tube that there is any perceptible reduction of thickness. With regard to the boiler tube there is another remark I may make. The boiler was worked for ten months without zinc, and then fearing that pitting would take place we had zinc blocks put in the boiler, and the boiler has since been protected by zinc blocks. In the boilers which were fitted to the Spanish boats there were zinc blocks put in them at first, and the engineer says internally there was no sign of pitting. The tube had that hole in it probably very nearly from the beginning. I do not think that was due to the same cause. I do not think that is so. With regard to the comparison of this boiler with the other model we have had before us, I would wish to point out a very considerable difference. I think we are indebted to Mr. Rowan for having invented this boiler, and I think we are indebted to everybody who has struggled in this direction, because it was a bold thing to make something so different from what had ever been used before. Mr. Rowan's boiler, as has been pointed out, gave an exceedingly high efficiency, details of which are given in Professor Rankine's papers. This boiler has one element of weakness that Mr. Parker has pointed out. Instead of there being a perfect circulation of the steam in the top, as there is in the water at the bottom, there is no efficient connection between the upper vessels, and, as Mr. Parker described, the increased firing in one part of the boiler drove the water out into another. Well, that very serious defect caused the boiler to explode.

Mr. W. Parker: May I say just one word in explanation? I beg to point out that that was not the cause of the failure of the boiler; the failure was due to pitting, and I distinctly stated so.

Mr. J. I. Thornycroft: Mr. Parker says that was not the cause. If Mr. Parker points out that the cause was pitting, I must still be allowed to say that if the water is driven out of these tubes, they would probably get nearly red hot, and if they do not pit they will rust at a very great rate, and I am inclined to think that this boiler was subject to pitting from another cause. I do not know at what level the water was carried in this boiler. I would like to ask Mr. Parker, if I may.

Mr. W. Parker: The gauge is shown here. The water level was about *here*. (*Indicating.*) This is an experimental model of a boiler for proving how the original one burst.

Mr. J. I. Thornycroft: This represents the level in the real boiler?

Mr. W. Parker: Yes; half way up that tube, so that when one section of the boiler was being fired harder than the other (as in the case of clearing fires) and the connecting steam pipe in the top not having been large enough to equalise the pressure in both sections, a greater pressure was produced in one than in the other, which forced the water out of the one into the other, the large tube immediately above the fire became red hot, and exploded.

Mr. J. I. Thornycroft: I thank Mr. Parker. Now what I am going to say about this boiler with reference to the water level is this: the tubes of this boiler are of considerable diameter. This is one of the tubes, and when this boiler is filled with water to the level Mr. Parker indicates, the heat of these tubes would cause circulation in these tubes, not always right round, but when the fires were not much forced. I take it that the water in these tubes would give off steam at the top, and be added to at the bottom, and within those tubes there would be an accumulation of any substance in the water, and on examining these tubes I found evidence that that is the case. This tube has a deposit in it of over one-eighth of an inch thick—I should be inclined to say nearly three-sixteenths of lime; and when that tube got that non-conducting coating inside it would get hot, although full of water. I am sorry I have not here the paper which I have prepared for the Institution of Civil Engineers, as it describes the circulation of the boiler which I have to show you. Where the tubes are of similar diameter, the same as we use, the water is unable to change places with the steam in the tube, and carries over with it any accumulation of deposit or matter that may be there; and the condition of the tubes that have been working in the North three years—I do not recollect how long Mr. Parker said this had worked—

Mr. W. Parker: They had worked a little over two years.

Mr. J. I. Thornycroft: That gives seven-sixteenths of an inch deposit in two years. The deposit in these tubes is hardly perceptible in nearly three, so that there is evidently some difference, and I say that it is a difference of circulation. Among the boilers that had failed were mentioned the *Montana* boiler. The *Montana* boiler was something like what was known as the Howard boiler. It consisted not of small tubes, as I propose, but of tubes of very considerable size. That boiler, I believe, failed through want of circulation, but as the meeting has been mostly of opinion that pitting is our principal enemy, I think we are justified in taking every advantage that is to be gained in fighting that enemy, and I hope we shall do so with success. Mr. MacGregor has had some experience of these boilers, and, although his experience has been confined to a merchant ship, he seems to think there is something worth fighting for in them. He has found economy of fuel, and great economy has been mentioned by Mr. Scott, who has had a great deal of experience in this kind of boiler. Mr. Scott

talked of the danger of cutting away the tube plate. Well, that particular question, of course, has been examined; we had a piece of tube plate tested, by being all cut away in holes as it was made, and we found that before that would break, the tube plate could be stretched until the holes were so large one way that no pressure could exist in the boiler; the tubes would simply have a moon-shaped opening on each side of them, so that I do not apprehend danger from cutting away the tube plate in the manner described. The question of running these boilers only a few hours has been mentioned, and it is said to be only fit for small boats, and so on. I am glad to be able to say that the boiler in fresh water has run about seven years, and our experience in the first trip of any length that these boats have made has been very satisfactory. We recently sent three boats to India, and the first boat made the voyage to Bombay in thirty-five days. She was also running at slow speed so as not to waste the fuel, because part of the voyage of 1,600 knots had to be made without taking coal—not a small duty in winter for a torpedo boat; but these three boats all went out with perfect safety, although one boat had a rough experience. That boat ran on a rock, but did not go down. She got off the rock, and was steamed back and repaired, and has finished her voyage. Mr. J. List has stated that the difficulty of pitting can be got over by using some other metal than iron. Iron or steel is best adapted to stand heat, and it is cheaper than any other metal. I do not think at present we are obliged to give up the iron, although I certainly, as Mr. List said, have thought of it. I certainly think iron can be made to stand, because iron has been made to last a long while. I think Mr. List told me that in their boats the tubes used to pit away until they attached the zinc to their boilers in a proper manner, securing electric contact in a very short time. Now they make a number of voyages without losing a single tube. I do not know that I have any more remarks to make on the subject.

The PRESIDENT: Gentlemen, it is my duty to convey your hearty thanks to our friend, Mr. Thornycroft, for his valuable paper, and I want particularly to congratulate one and all of you upon the discussion that has followed upon that paper. It has been conducted by men whose equals, I think, you could hardly find—men in charge of our great ocean steam lines; and, in fact, the discussion has been conducted, I think, with an ability that leaves nothing to be desired. It has been a most valuable one; and, as a matter of history, gentlemen, I will refer for a moment to the day. We have sat a longer number of hours than I believe this Institution has ever sat in one day before, and yet so great has been the interest, and so important the subjects brought before you, that I am quite sure there is no gentleman, and I hope no lady, in this hall, who grudges the patience and the time which has been expended upon these discussions. They have been of immense national value, and I congratulate you upon the success of this day's work.

ON EXPERIMENTS IN ENDEAVOURING TO BURST A BOILER SHELL MADE TO ADMIRALTY SCANTLINGS.

By John Scott, Esq., C.B., F.R.S.E., Member of Council.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 11th, 1889; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

At the twentieth Session of this Institution, in 1888, a paper was read by Mr. Richard Sennett, R.N., Member of Council and Engineer-in-Chief of the Navy, on "Working and Test Pressures of Marine Boilers."

The reading of this paper evoked considerable discussion, and the expression of large difference of opinion among members of the Institution.

It seemed possible that a practical experiment in the direction of endeavouring to burst the shell of a new steel boiler might throw some light on the subject, and furnish the proverbial ounce of fact so superior to the pound of opinion. Not a few old iron boilers, most of them having worked at low pressures, have, from time to time, been submitted to bursting pressure by various engineers, and Mr. Sennett's paper stated that he had officially conducted a number of such experiments with naval boilers. No record, however, appears to exist of any bursting experiment made with the shell of a new boiler of a size used in actual practice, constructed of steel, and intended to work at the pressure now in common use.

The experiment detailed in the paper was accordingly resolved on, and was carried out at the Greenock Foundry.

During last summer, boilers were being made at that establishment for H.M. gun-vessels *Sparrow* and *Thrush*, intended for a working pressure by Admiralty specification of 145 lbs. per square inch. The diameter of these boilers was such that an experiment on a shell of duplicate diameter could be conducted without incurring too serious expense. A shell of the dimensions shown on Figs. 1, 2, and 3 (Plate XXIX.), was accordingly constructed, having the same mean diameter (7 ft. $8\frac{3}{16}$ in.), the same thickness of plating, disposition of riveting and longitudinal stays, as the boilers of the *Sparrow*

and *Thrush*.* The experiment being only to test the shell plating, no furnaces, combustion chambers, or tubes were fitted. The ends were of uniform shape throughout, with stays similar to those in the upper portion of the boilers being made for actual use.

The number of plates and the distribution of butts in the experimental shell are identical with the *Sparrow* boilers, but the total length of this boiler was made 11 ft. instead of 16 ft. 9 in. The plates and stays used were subjected to the usual Admiralty tests for tension, and as shown on Table I.

No special precautions were taken in regard to the workmanship other than is usual at the Greenock Foundry in manufacturing boilers for the Royal Navy or the merchant service. The flanged ends were pressed by the Leeds Forge Company's hydraulic press at one heat, and were not annealed. The shell plates were bent cold. The rivet holes were bored in place after bending. The riveting of one end and the shell plates was done by hydraulic machine, adjusted to a pressure of 120 tons on each rivet. The closing end was riveted by hand. The boiler was caulked in the usual way, and prior to commencing the experiment it was tested for tightness to the pressure required by the Admiralty specification for this class boiler, viz., 235 lbs. per square inch.

Preparation for Trial.

The boiler was set on chocks, surrounded by a strong framework of wood, forming straight edges at six different positions, and observations were made at a large number of places, as shown on Figs. 1 and 3, by which the changes in form, which resulted at the various trials, were read off and transferred to the drawings.

First Trial.—Pressure was raised to 145 lbs. per square inch, being the intended working pressure. A slight alteration of form was registered, probably arising from the effort of the boiler to assume a true cylindrical shape, by which some parts of the boiler appeared to increase in diameter and others to diminish—as recorded at the observation stations. Pressure was then raised to 235 lbs., the Admiralty test pressure, and produced the alteration in form shown on Table II., and continued up to 300 lbs. per square inch without any leak occurring. Pressure was then reduced to zero, and the boiler returned to its original figure, as noted at each of the test spots. Pressure was again applied, and raised gently till 330 lbs. per square inch was reached, when leaking commenced to a small extent through the manhole door; all the other portions of the boiler remained tight. Pumping was then continued to 450 lbs. per square inch, at which point the volume of water supplied by four pumps was equalled by the leakage from the manhole, and the trial had to be suspended. The remainder of the boiler was tight, except a very small leak from one of the corners of each of two butts. On

* Thickness of shell plates, $\frac{1}{2}\frac{3}{2}$ in.; of butt straps, $\frac{1}{2}\frac{1}{2}$ in.; of boiler ends, $\frac{3}{3}\frac{3}{2}$ in.; of washers, $\frac{3}{3}\frac{9}{2}$ in.; of manhole strengthening plate, $\frac{3}{3}\frac{9}{2}$ in.

examination, the strengthening plate surrounding the manhole door was found to be buckled, and the caulking round the edges started. This plate was then removed, and a large plate fitted (as shown on Plate XXIX.), secured by rivets spread over its surface. The permanent set assumed by the boiler at this stage is shown in Tables II., III., and IV. No other repair was made.

Second Trial.—Pressure was raised from zero to 350 lbs. per square inch, without any leak. At this stage a slight leak recommenced at the manhole. Pressure was continued until it reached 520 lbs. per square inch, when the leakage overcame the supply from the pumps. In addition to leakage from the manhole, leaks of some extent were visible at the ends of all the butt straps, but all other portions of the boiler remained tight. The permanent set found after this pressure is recorded in Tables III. and IV. On examining the stays inside, those of the centre within the dotted circle were found to be reduced in diameter $\frac{1}{64}$ in., but with great regularity throughout their length. The centre of the boiler had lengthened about 1 in. at each end. No starting of the butt straps was visible either externally or internally. The butt straps were caulked on the ends, and an increased number of bolts fitted to the manhole door, which was re-caulked.

Third Trial.—Pressure raised to 350 lbs. per square inch, at which the boiler was tight. The pressure was then raised continuously until 580 lbs. was reached, the same causes again arresting the trial. Leakage commenced at the manhole at about 360 lbs., and gradually increased until the terminal pressure of the day was reached. Larger leaks were observed on the ends of the butts, and very slightly at some portion of the sides of the butt straps, and also very slightly through the stay nuts, and at their bases. On examination, no visible change had taken place in the caulking of the butts outside, but the end of the inside butt straps were about $\frac{1}{64}$ in. open, and the caulking of the straps inside had started as observable by the eye, but not sufficiently to permit the insertion of the thinnest testing knife. The stays within the black dotted circle of the drawing, Fig. 3, showed a reduction of about $\frac{2}{64}$ in. nearly from their original dimensions, and spread evenly over the whole length. Bulging of ends and permanent set of shell are noted in Tables III. and IV. Butts were caulked, and three additional pumps were connected to increase the water supply.

Fourth Trial.—Boiler tight at 350 lbs. Pressure continued and slight leakage commenced before 400 lbs. was reached. Pressure rose rapidly in consequence of the large water supply, but leaks increased at the sides and ends of all the butt straps as the pressure reached 620 lbs. per square inch. Although this pressure was maintained for five minutes, it could not be increased, and the trial had to be stopped. With the exception of one or two rivets showing slight signs of leaking, the riveting throughout remained unimpaired, and in this respect no difference can be detected between the hand riveting and the machine riveting. The final permanent sets are given in Tables III. and IV.

The mean tensional strength of the shell plates and butt straps, as plates before bending, may be taken as 61,500 lbs. It will be observed from Table VI. that at 620 lbs. per square inch of internal pressure the section of the plate left after rivet holes are bored was strained to 57,504 lbs., or 93½ per cent. of the strength of the solid plate, and without rupture or serious disturbance of the structure. To the eye the butt straps appear to be uninjured. This result may tend to show that it is possible, in a circular structure, a doubled strapped butt, joining plates supported at the edges by solid plate, may be capable of sustaining a higher percentage of strain than straight samples of a similarly arranged butt without side support, which may have been pulled to destruction on a testing machine.

The conclusions stated by several Members of the Institution in the debate on Mr. Sennett's paper, that extemporised safety valves would spring into existence in a steel boiler exposed to extreme pressure, seems to be borne out by the results of this experiment.

It will be observed from the drawing and Table V. that although the two circumferential seams have increased in diameter to the extent of $\frac{1}{16}$ and $\frac{5}{8}$ in., they have otherwise maintained their form, and extended in a much less degree than the single plate intervening between two of them, which has barrelled to a considerable extent. In the case of the boilers of the *Sparrow* and *Thrush* a different action was set up at the proof pressure of 235 lbs. per square inch. From the counteracting effect of the staying of the fire-box, which is placed near the centre of the boiler, the top and bottom of these boilers tended slightly inwards in a regular curve from end to end, while the sides were correspondingly extended. Attention may be called to the drawing and Table III., showing the permanent set of the boiler ends, which have assumed a fairly regular curve from the circumference to the centre.

In the official experiments made by the Board of Trade, and detailed in Memorandum for the Information of Board of Trade Surveyors, 1881, an account is given of the breaking of a flat box with short stays supported by riveted washers. The form of the permanent set of the plate is entirely different from that experienced in the test boiler now under consideration, due to the length of the stays. The drawing exhibiting the Board of Trade experiment shows the stress to have been developed locally between the stays in quasi-spherical shape, while the test boiler has assumed a regular curve throughout, from centre to circumference. While in practice the longitudinal stays in common use are probably sufficiently strong, it may be assumed that theoretically their diameter should be increased to correspond with the length of the boiler.

While the various portions of the test boiler seem to have acted in harmony, and to have shown no special line of weakness at any point, it may be remarked that at the

butt straps, arranged as they were to obtain a percentage of 83·7 per cent., the wide spacing of the rivets, which on the edge of the straps are 5¾ in. from centre to centre, through ½ in. butt straps, may have determined the tendency to leak at the edges, which ultimately manifested itself as noted above. While this spacing may be suitable for ordinary or test pressures, it may not be that which will permit a maximum amount of tightness to be reached at the highest pressures. The resistance of the riveting throughout in this test goes far to show that this portion of boiler construction can be relied on at extreme pressure. The modern style of workmanship has brought the weaker parts of the structure more into harmony with the solid plate, and reduces the whole structure into a more homogeneous state than existed when the factors of safety, still in vogue with the Classification Societies and the Board of Trade, were fixed on.

The experiment which this paper has endeavoured to describe seems to present some justification for a reduction in the minimum scantlings of the shells in marine boilers of merchant service to at least the scale now adopted by the Admiralty.

TABLE I.

Result of Steel Tests.

For what part used.	Tensile strength in tons per square inch.	Elongation in 10 inches per cent.
Flanged end	28·1	25
,, ,,	27·3	25
End plate of shell	26·9	29
,, ,, ,,	27·8	25
Middle ,, ,,	27·7	25.2
Butt straps	26·2	27
Manhole strengthening plate	26·7	In 8 in. per cent. 26·6
Boiler stays	26·8	

TABLE VI.

Stresses on Boiler at Various Pressures.

Internal pressure in lbs. per square inch..	130	135	145	235	300	450	520	580	620
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Stress on shell per square inch of solid plate	10,092	10,480	11,256	18,243	23,288	34,933	40,367	45,025	48.130
Stress per square inch of section left after rivet holes are bored	12,057	12,521	13,448	21,796	27,824	41,737	48,229	53,794	57,504
Stress on rivets in longitudinal seams per square inch of section (double shear)...	8,320	8,640	9,280	15,040	19,200	28,800	33,280	37,120	39,680
Stress on stays, per square inch of section	8,910	9,253	9,938	16,107	20,562	30,843	35,640	39,753	42.494

Average tensile strength of boiler plates in lbs. per square inch = 61,500.

TABLE II.

DEFLECTION AT VARIOUS PRESSURES WITHIN THE LIMITS OF ELASTICITY, IN 64THS OF AN INCH.

Point.	145 lbs.		235 lbs.		300 lbs.	
	In.	Out.	In.	Out.	In.	Out.
No.						
1	..	2	..	4	..	5
2	..	2	..	3	..	6
3	..	1	..	3	..	4
4	..	1	..	2	..	3
5	..	1	..	2	..	3
6	4	..	6	..	8	..
7	3	..	4	..	4	..
8	4	..	3	..	3	..
9	4	..	6	..	6	..
10	4	..	7	..	7	..
11	4	..	6	..	6	..
12	4	..	6	..	6	..
13	4	..	6	..	6	..
14	6	..	8	..	8	..
15	..	2	..	3	..	4
16	..	2	..	3	..	4
17	..	2	..	3	..	4
18	..	1	..	2	..	4
19	..	2	..	3	..	4
20	..	4	..	6	..	8
21	..	4	..	6	..	10
22	..	4	..	6	..	9
23	..	5	..	8	..	10
24	..	4	..	6	..	8
25	..	4	..	7	..	10
26	..	4	..	7	..	8
27	..	4	..	6	..	8
28	..	4	..	6	..	8

TABLE III.

PERMANENT BULGE ON BOILER ENDS, AT VARIOUS PRESSURES, IN 64THS OF AN INCH.

Point.	450 lbs.	520 lbs.	580 lbs.	620 lbs.
No.				
1	8	40	76	98
2	16	53	92	112
3	20	66	104	120
4	20	52	92	120
5	12	40	76	104
15	12	40	74	92
16	20	50	90	100
17	18	64	104	112
18	14	50	90	112
19	8	38	74	100

TABLE IV.

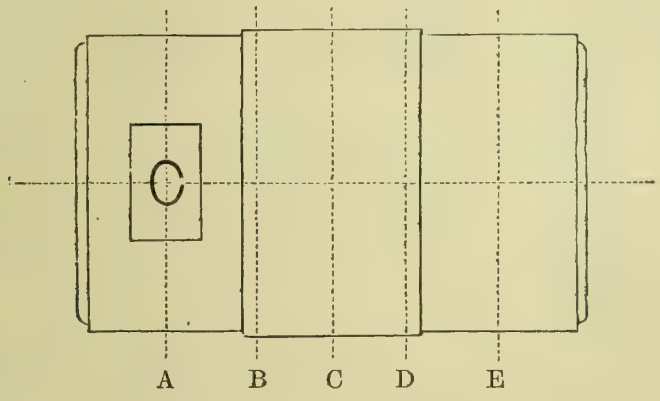
PERMANENT BULGE ON BOILER SIDES, AT VARIOUS PRESSURES, IN 64THS OF AN INCH.

Point.	450 lbs.	520 lbs.	580 lbs.	620 lbs.
No.				
6	4	6	4	4
7	7	4	40	52
8	6	1	32	48
9	6	1	6	20
10	7	3	16	36
11	5	2	8	24
12	8	28	52	60
13	16	45	64	64
14	4	12	4	2
20	..	2	4	2
21	4	22	40	42
22	4	14	36	38
23	..	10	2	34
24	..	2	21	60
25	..	..	6	26
26	..	4	18	30
27	..	12	28	34
28	..	1	6	2

TABLE V.

Permanent Increase in the Diameter of Boiler at Various Pressures.

Pressure in lbs. per square inch.	400 lbs.	520 lbs.	580 lbs.	620 lbs.
	in.	in.	in.	in.
Mean increase in diameter at A	$\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{5}{8}$	$1\frac{13}{16}$
Do. ,, ,, B	..	..	..	$\frac{11}{16}$
Do. ,, ,, C	$\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{5}{16}$
Do. ,, ,, D	..	..	..	$\frac{5}{8}$
Do. ,, ,, E	$\frac{3}{16}$	$\frac{1}{4}$	1	$1\frac{1}{4}$



The bulging of the shell (A) in the neighbourhood of the manhole, which was very irregular, is shown on the transverse section of the boiler through the manhole, Fig. 4 (Plate XXIX.).

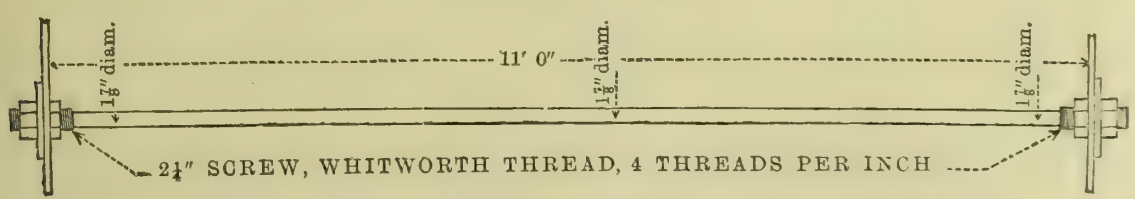
TABLE VII.

Permanent Set on Stays at Various Pressures.

Pressure per square inch.	520 lbs.	580 lbs.	620 lbs.
Greatest elongation of stays in inches	$2\frac{1}{2}$ in.	$3\frac{1}{8}$ in.	$3\frac{3}{8}$ in.
,, reduction in diameter	About $\frac{1}{64}$	About $\frac{2}{64}$	About $\frac{4}{64}$ bare.

The reduction in diameter of stays was uniform throughout their length to within 8 inches of the ends, from which they tapered up to their original diameter, and was greatest in the stays nearest the centre of the boiler.

Particulars of Stays.



Washers 10 in. diam. × $\frac{5}{8}$ in. thick. Eight $1\frac{3}{16}$ in. rivets in each washer.

DISCUSSION.

Mr. John Scott, C.B. (Member of Council): Sir John Hay and gentlemen, you will perhaps allow me to offer one observation in extension of this paper which occurred to me after I sent in the manuscript for printing. It is this, that an examination of the tube shows the extensions that have taken place in the various tubes of the three rings of the boiler which are extremely marked. Anyone who is good enough to visit the boiler I shall be extremely happy to show it to. Each of the streaks of the plates one, two, and three, as marked in the drawing, has assumed a barrel form, the ordinates of which you will find in the table. I shall wish to express in continuation of the paper that that examination of the manner in which extension may take place under extreme pressure may possibly form a good reason for the reduction of the breadth of the plating now being so much used by engineers in the construction of their boilers, as it is well known to all marine engineers here present that in constructing double-ended boilers of large length, probably up to nearly 18 ft., it is a common practice at present to use plates up to 6 ft. in breadth. The result of this experiment may show that in doing so, engineers are extending the limit of safety in that direction a little far. It is evident from the experiment made here that lines of strength are formed by the circumferential seams of the plates, and it may be the case that the ultimate width to which plates may with safety be extended require consideration on the part of those who are designing boilers.

The Chairman: I have much pleasure in calling upon Mr. Parker.

Mr. W. Parker (Member of Council): Sir John Hay and gentlemen, recalling the active part I took in the discussion on this subject twelve months ago, I would now prefer to make any remarks I may have to offer a little later on.

Mr. Alexander Taylor (Member): I am sorry to say that I can say nothing on this subject but express my thanks to Mr. Scott for the experiments which he has made, and for giving us the information which he has laid before us.

Mr. G. W. Manuel (Member): My Lord and gentlemen, the short time given me to study this paper is my excuse for the few remarks I desire to make, and chiefly with regard to the value of this experiment, which, I understand, has been made to substantiate in practice the views expressed by Mr. Sennett, in his paper read before this Institution last year—viz., that the cylindrical shell-plating of a marine boiler, fit to work only at 110 lbs. pressure of steam per square inch by the Board of Trade, and 120 lbs. by Lloyd's rules, was considered fit to work at 155 lbs. steam pressure per square inch by the Admiralty rules. I observe that the drawing of the boiler shown by Mr. Scott represents only part of a marine boiler—viz., the circumferential shell-plating, and is a duplicate of the shell-plating of a boiler constructed for a vessel for the Royal Navy by this gentleman, the working steam pressure of which was to be 145 lbs. per square inch; and, according to Mr. Sennett's paper of last year, it was fit for only 115 lbs. steam pressure per square inch by Lloyd's rules, and 110 lbs. ditto by the Board of Trade. I consider it would have been desirable if Mr. Scott had given this Institution also an exact drawing of the boiler complete, showing furnaces, combustion chambers, and staying "as it was fitted." The experimental shell-plating, with the ends here shown, are so geometrically stayed that the internal strains are equally diffused, tending to keep the circumferential shell-plating longer in position under pressure during the test; whereas, in the "actual boiler" the staying would be irregular in position, and of quite a different character, and the circumferential shell-plating itself would be also used at different parts to attach the usual stays supporting some of the internal parts of the boiler, such as fire-box and combustion-chambers, thus causing unequal strain on the circumferential shell; and this, coupled with the strains due to the high temperature of some parts of the boiler, I think would give quite different and inferior results from those shown by these tests, and which require to be allowed for in the factor of safety.

Mr. JOHN SCOTT: I regret extremely that these plates were not absolutely tested. I may say that the plates being made almost simultaneously for the *Sparrow* and the *Thrush* were tested for the elastic limit, and reached 16½ tons. They were made at the same works. It was an omission at the time not to test the elastic limit of those intended for the experimental boiler.

Mr. G. W. MANUEL: The circumferential shell is part of the boiler having a number of stay attachments usually fixed in it supporting the internal parts, which, therefore, subject this shell to different strains than those simply due to its spherical form as shown in the diagram, and which should not be considered separately. I note that when tested by hydraulic pressure, as recorded in the tables showing the results, the shell-plating had a considerable alteration in form, and permanent set at 450 lbs. pressure per square inch, equal to three times the working pressure, and leaked at the ends of the circumferential butt straps; and at 520 lbs. pressure per square inch the leakage was too much for the pumps to keep up the pressure, and from my experience I have no doubt there were movements of the different parts, and also the riveting, some time before this pressure was reached, and at a much lower pressure, as indicated by Table No. II., and for continuous steaming this state of things should not be approached, and does not justify such a reduction of the factor of safety as proposed; I can quite understand that in order to carry numerous and heavy armaments, and keep up high speeds in the larger vessels of the Royal Navy, there is a desire to reduce the weights of the propelling machinery, including the boilers, and although I think the scantling of the boiler sheets may be reduced slightly along with improved material, it should not be to the extent advocated by Mr. Sennett in his paper of last year. It must be taken into consideration that the use and working of marine boilers in the large vessels of the Royal Navy are entirely different to what they are in the Merchant Service; in the former, boilers are under full work from two to five days in the year at the most, and for twelve hours at a time, whereas in the latter service, and also that of the mail services, the boilers are under work and full pressure for 220 days in the year, and for thirty-five days continuously at a time. Such boilers are expected to last for fourteen years. I therefore think that for continuous working such a reduction of scantling of the shell is undesirable, and it would be better if higher pressures are required to alter the form of the boilers to something more approaching the tubulous type. Having had considerable experience in testing practically the circumferential shell seams before the present rules were formulated for steel boilers, it came to my notice that with mild steel, say, of about 28 tons tensile strength, and with mild steel rivets of about 19 tons shearing strength with an elastic limit for this steel as low as 15 tons per square inch, movements took place in the material when under test much earlier than was then generally known, and at pressures approaching too near the working pressure of steam. It would have been useful if Mr. Scott had given the meeting the elastic limit of the steel used in his experiment for the shell-plating and stays. From the table of the steel tests it appears to have a tensile strength varying from 26·2 tons to 27·8 tons per square inch, and, therefore, the elastic limit of this mild steel may be taken as low as 14 to 16 tons per square inch, and this, along with the mild steel rivets, would cause stretch and compression under a stress too near the working pressure.

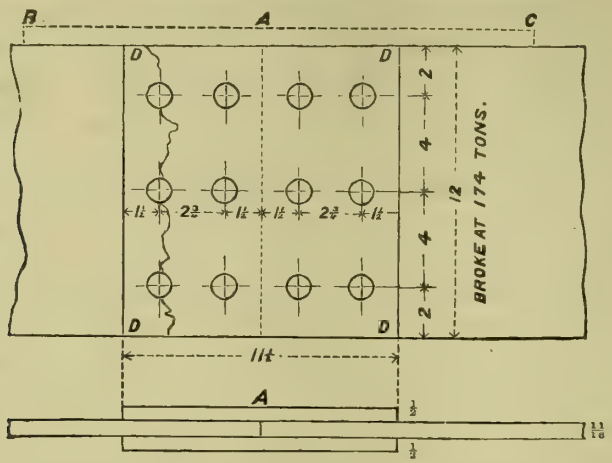
Mr. W. H. WHITE, F.R.S. (Vice-President): May I ask Mr. Manuel if he could give us any corresponding facts within his knowledge of tests made on boilers with heavier shells. I am not going to speak on the paper. Mr. Manuel has said he thinks this has gone too far.

Mr. G. W. MANUEL: Yes. I will be pleased to do so.

The CHAIRMAN: Perhaps Mr. Manuel will append these results when he forwards his remarks to the Secretary to be embodied in the Transactions.

Mr. MANUEL, replying, said he would be pleased to do so. (Copies of the tests referred to here follow.)

No. 1.—Longitudinal Seams, Chain Riveted Joints.



Sketch of Test Pieces, Shell Seams, Broken by a Stress of 174 Tons.

TABLE I.

Experiment with Chain Riveted Joints.

Stress.	Opened at A	Stretched between B & C	Remarks.
W.P. = 65 lbs. = 27 tons	0 On specimen	0	
2 W.P. = 130 lbs. = 54 tons	$\frac{1}{16}\frac{1}{4}$ in.	$\frac{1}{16}\frac{1}{4}$ in. F.	Permanent set began.
3 W.P. = 195 lbs. = 81 tons	$\frac{1}{32}$ in.	$\frac{1}{16}$ in. B.	Permanent set very decided.
4 W.P. = 260 lbs. = 108 tons	$\frac{1}{32}$ in.	$\frac{1}{16}$ in.	
5 W.P. = 325 lbs. = 135 tons	$\frac{1}{32}$ in. F.	$\frac{1}{16}$ in. F.	
140 tons	$\frac{1}{16}$ in.	$\frac{3}{32}$ in.	
150 tons	$\frac{1}{16}$ in.	$\frac{1}{8} + \frac{1}{32}$ in.	Commenced to reduce in width at D.
6 W.P. = 390 lbs. = 162 tons	$\frac{3}{32}$ in.	$\frac{3}{16} + \frac{1}{32}$ in.	
164 tons	$\frac{3}{16}$ in.	Not taken	
174 tons	Not taken	Not taken	Gave out at transverse line of rivet holes, as per sketch.

This portion of a circumferential longitudinal seam is a duplicate of the actual seam of a marine boiler constructed to carry a working pressure of 65 lbs. per square inch. It was tested to destruction by a powerful testing machine in Lloyd's proving-house, Low Walker-on-Tyne, and eventually the plate broke through the rivet holes, and crushed the rivets under a stress of 174 tons.

Area of plate section = 6·05 square inches.

Area rivet section = 5·09 square inches.

Tensile strength of plate as broken, 28·7 tons.

Elastic limit on section, $15\frac{3}{4}$ tons.

Steel, Siemens mild steel.

Shearing stress of rivets = 19 tons.

While in the machine the alterations that took place under the various stresses were carefully taken at A, B, and C by me, and as noted in Table I.

The load of 27 tons was first applied, being equal to 65 lbs. per square inch, to the working pressure of the boiler, when no alteration took place. At 54 tons, or equal to twice the working pressure (usually the cold water test pressure), the joint opened at A, where the plates butt, and stretched between B and C $\frac{1}{64}$ inch; and at 81 tons stress, or equal to three times the working pressure, permanent set began, due to plate and compression of the rivets. At 108 tons stress, or four times the working pressure, the joint was to all intents and purposes "crippled," though it did not break till a stress equal to 174 tons was applied; at that stress the joint was stretched and rivets compressed considerably out of its original form.

I give in the following Table II. the results of five out of a number of tensile tests of this same mild steel cut out of plates used in the boiler in question, which show that the limit of elasticity, or its vitality, ceased at a low stress, except in specimen No. 5, showing that it is desirable to use steel of a higher tensile strength for boiler shells, say 29 and 30 tons, possessing also ductile qualities sufficient for the purpose of boiler work.

TABLE II.

No. of Test.	Sectional Area, in Square inches.	Tensile strength per square inch. Tons.	Elastic limit per square inch. Tons.
1	1·228	25·6	13·8
2	0·717	26·5	14·0
3	1·144	27·5	15·0
4	1·288	28·3	15·5
5	0·936	29·3	18·1

The steel used in the shell-plating of Mr. Scott's experiment had, as per his Table I., a tensile strength of 26·2 to 27·8 tons per square inch, and, as I have stated, the elastic limit may be taken at from 14 to 16 tons—too low for the pressure to be carried on the boiler in question, viz., 145 lbs. per square inch.

Mr. J. List (Member) : Sir John Hay and gentlemen, these experiments which have been carried out at the Greenock Foundry Company's Works by Mr. Scott, are extremely interesting, because they bear out to some extent the views held by many engineers as to the desirability of reducing the thickness of the shells of high-pressure marine boilers. When we have to deal with large double-ended boilers, say 14 ft. 9 in. diameter, for a pressure of 160 lbs. per square inch, the shells, if made to the Board of Trade rules, are no less than $1\frac{5}{16}$ in. thick, with steel of an ultimate tenacity of about 30 tons per square inch. If, therefore, from data derived from experiments such as this, it can be proved that thinner shells may be adopted with confidence, then the gain both to the makers and users of the boilers will be considerable. As Mr. Manuel has just pointed out, the vessel upon which these experiments have been made does not strictly represent a marine boiler, inasmuch as it has neither flues nor tubes. Considering, however, the expense attending the testing to destruction of a new and complete high-pressure marine boiler, I think it is hardly to be expected that such an experiment would be readily undertaken by any firm at their own cost. Moreover, it appears to me that for the purpose intended, that is, to obtain accurate data as to the ultimate strength, and also the tightness of the shell, only this form of experiment fully meets the case. I wish, however, to ask one or two questions as to the details of construction. The longitudinal seams are double strapped, but the riveting appears to me rather different from that usually adopted in the thick shells of boilers made to the Board of Trade rules.

Mr. John Scott : It is one of the Board of Trade forms of joint.

Mr. J. List : The arrangement of rivets, which is, I think, more often adopted in treble riveted straps, is to have the pitch double the width in the outer row. The only bearing which this might have would be, I think, in connection with the tightness of the joint at pressures considerably above the usual test pressure. Another point upon which I should be glad to have further information is this : How are the ends of the butt straps finished ? Are they tucked under the edges of the adjacent wings of the shells ? as that also bears on the question of the tightness of the joints.

Mr. John Scott : They are tucked under.

Mr. J. List : It would be interesting if a corresponding experiment were made with a shell in which the straps between the wings are made of the same thickness as the shell, and merely butted, the end butts being covered by doubling plates. This method of construction is sometimes used, and it is an open question whether it has any advantage over the system of tucking under.

Mr. John Scott : These straps are tucked under as far as the first line of rivets in the circumferential seam.

Mr. J. List : That, no doubt, is the general practice ; but the other plan, to which I have alluded, has the advantage of avoiding the work of cutting the recesses in the plate edges for the ends of the straps. On the other hand it makes a somewhat heavier boiler. I observe also that the circumferential seams in this experimental boiler are only double riveted. It is now usual to treble rivet them, except at the ends of the boilers. Possibly the support which the wider treble-riveted seam would afford to the adjacent longitudinal seams would show even a higher strength in those joints when tested to destruction. The only other important point in which this boiler differs from the usual construction is in having longitudinal stays with plus threads, and in having the washers riveted to the plates. From certain practical objections to welding or upsetting such stays, the more usual practice now is to make the stays with minus threads, and to keep the thickness of the end plates up to

what is required for loose washers only. Had the boiler under consideration been constructed in that way, no doubt the behaviour of the end plates under the maximum pressure reached would have been somewhat different. The method of construction which has been adopted is no doubt, however, that which uses a given weight of material to the best advantage, though it may not commend itself as regards first cost, or up-keep of the stays against corrosion, which corrosion is not so easily prevented in the stow space as it is below the water line in the boiler.

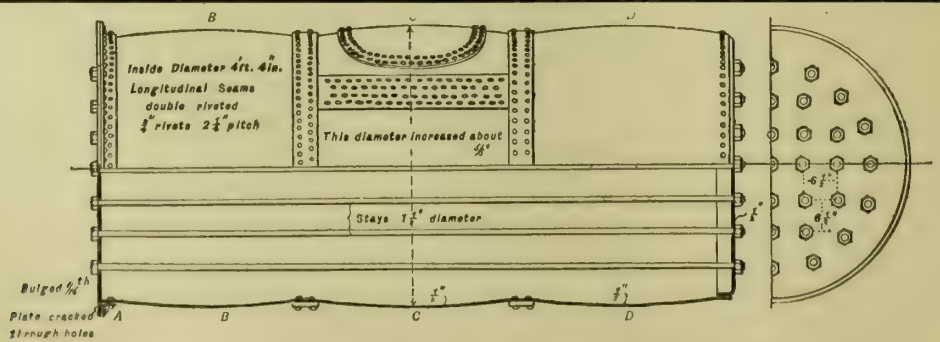
Admiral A. F. R. DE HORSEY (Associate): This is so exclusively a question for engineers that I do not propose to make any remarks upon it. But, seeing that explosions of boilers are largely due to the unequal expansion of their various parts, I should like to ask Mr. Scott to tell us, when he replies, whether he does not consider that rupture or leakage might ensue from a very much less pressure of *steam* than that exerted by *water pressure* in the cold test. I ask this question in the interest of those who may have to go to sea in ships with boiler shells of reduced scantling, as there is, in these days, every tendency to reduce the material to the very finest limits.

Mr. W. PARKER (Member of Council): Sir John Hay and gentlemen, I did not intend to say much this evening on this important subject. I came rather to listen than to speak; but, as this experiment appears to have been an outcome of the very interesting paper read by my friend Mr. Sennett, and also the very interesting discussion that took place a year ago, I feel bound to say a few words. In the first place, I am reminded by Admiral De Horsey's question of a point to which I wish to call the attention of the meeting, and I will, with your permission, refer to it at once. Admiral De Horsey asks—and, perhaps, Sir John Hay, I am not out of order in answering his question—whether a structure such as a cylinder tested under cold water pressure to destruction would be under the same conditions, and, if burst, have the same effect, as a similar structure burst by steam pressure. I venture to think, and I submit it for the consideration of this meeting, that every steam boiler explosion—and numbers of them occur on land every year—has proved the effect of steam pressure to be very different from that of water pressure. Whenever the circumstances attending the explosion of the shell of a steam boiler have been investigated by the practical investigators and engineers of the various Boiler Insurance Companies, the violent tearing of the plates, pieces of which are sometimes thrown to great distances, has always been rightly ascribed to the tremendous expansive force pent up in the steam. The effect would, of course, be very different if a boiler were tested to destruction by cold water pressure. Still, any experiments on the behaviour of a boiler under pressure, even water pressure, must be very acceptable to all marine engineers. I for my part take great interest in them, and I thank Mr. Scott for bringing the result of these interesting experiments before us. In passing, I cannot but notice the third paragraph of Mr. Scott's paper, in which he says: "No record appears to exist of any bursting experiments made with the shell of a new boiler of a size used in actual practice constructed of steel and intended to work at the pressure now in common use." I must take exception to that statement, and in doing so I cannot help thinking that Mr. Scott has, perhaps, not read our Transactions very carefully, for so far back as 1878 it was my privilege to read a paper in this room on the use of steel for marine boiler-making purposes, at the time when the first boiler was being constructed of that material; and I stated in that paper that, at the request of the late Sir William Siemens, a boiler of an experimental type, not such as Mr. Manuel would like to see tested, although, perhaps, that would be even more instructive, but a boiler similar to the one Mr. Scott has experimented upon, was made of mild steel and tested to destruction at the works of the Great Western Railway Company at Swindon by Mr. Dean, the Locomotive Superintendent. The form of this boiler is shown in the diagram, and the results of the test are given in the annexed table:—

Test of Experimental Steel Boiler.

Description of Boiler.—Length inside, 10 ft. 6 in.; diameter inside, 4 ft. 4 in. Plate, $\frac{1}{2}$ in. thick; bands, 5 in. wide, $\frac{9}{16}$ in. thick, two rows of $\frac{3}{4}$ in. rivets. Thirty-seven longitudinal stays (steel) $1\frac{1}{2}$ in. diameter, with $1\frac{3}{4}$ in. ends, and nuts. Angle iron at flat ends; Low Moor iron, 3 in. × 3 in. × $\frac{1}{2}$ in. full. Flat end plates (steel) $\frac{1}{2}$ in. thick.

Order of Test.	Pressure per square inch in lbs.	Increase in circumference at bands in inches.	Increase in diameter.	Bulging of end plates (flat).	Bulging of end plates (flanged).	Result.	Remarks.
1st	252	Nil.	Nil.	Nil.	Nil.	Tight.	
,,	336	$\frac{1}{32}$	Not perceptible.	,,	,,	One longitudinal stay leaking, 3 rows from bottom. One ditto, ditto, at top.	Stopped test, and took off nuts of stays to caulk.
2nd	336	$\frac{1}{64}$	,,	,,	,,	Tight.	
,,	448	$\frac{1}{16}$	,,	$\frac{1}{8}$	,,	Tight.	
,,	560	,,	,,	$\frac{1}{8}$	,,	Leak at brass plug.	
,,	616	,,	,,	$\frac{1}{8}$	,,	Heavy leak at brass plug, rivets in band, and angle iron ring.	Stopped test, caulked band nearest flat end of boiler, and tightened brass plug.
3rd	616	Not gauged.		Not gauged.		Tight.	
4th	616	$\frac{1}{16}$	Not gauged	$\frac{1}{8}$	nil.		
,,	694	..	,,	$\frac{1}{8}$	,,		
,,	728	$\frac{1}{8}$ full	,,	$\frac{3}{16}$	,,	Band split transversely 1 in. between rivets; brass plug leaked badly, owing to hole in plate; elongating flat plate cracked for 2 ft. 6 in. length between rivet holes.	Permanent set at flat end $\frac{1}{16}$ in.
5th	336	..	..	$\frac{3}{16}$	nil.	Slight leak at crack, rivets ditto, flat end.	
,,	588						
,,	700	Not gauged.		Not gauged.		Sharp crack; flat plate broken between rivets; leaking badly.	
,,	784						
,,	795	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{5}{16}$	..	Crack in flat plate; leaking badly; rivets leaking; hole in plate, with brass plug for pressure drawn oval, and leaking badly, so much so as to render it impossible to increase the pressure.	



Inside diameter, 4 ft. 4 in.; Length, 10 ft. 6 in. The greatest increase in diameter was $\frac{5}{8}$ in.

These results seem to indicate that in consequence of the great stretch of the material, the leakage at the joints of a steel boiler, even although double butt strapped, would give warning of the excess of pressure long before the bursting point is reached. I think that is a very similar experiment to the one Mr. Scott has made. I must also, I think, make one or two remarks with regard to the last paragraph but one in this paper, commencing: "The modern style of workmanship has brought the weaker parts of the structure more into harmony with the solid plate, and reduces the whole structure into a more homogeneous state than existed when the factors of safety still in vogue with the classification societies and the Board of Trade were fixed on. The experiment which this paper has endeavoured to describe seems to present some justification for a reduction in the minimum scantlings of the shells in marine boilers of merchant service to at least the scale now adopted by the Admiralty." At the discussion twelve months ago I expressed my views, perhaps, too freely on that particular subject, and it is not my intention now to repeat them; but since receiving this paper, which was only late last night, I have calculated the working pressure that would be allowed by Lloyd's rules in the boiler experimented upon by Mr. Scott, and I find that it would be 135 lbs. per square inch, while the intended working pressure was 145 lbs. per square inch. Perhaps Mr. Scott would check the figures.

Mr. John Scott: That is quite right.

Mr. W. Parker: That is a difference of $7\frac{1}{2}$ per cent., but surely it is not what was represented to us last year as the Admiralty rule. It is stated that this boiler is made according to the Admiralty rule for 145 lbs. working pressure. If I am in error I hope to be corrected; but if my calculations are right, according to the rule laid down in the paper last year the pressure would not be 145 lbs. but 180 lbs. per square inch. I am open to correction, and I hope that other speakers will put me right on the point if I am wrong. I believe the rule given by Mr. Sennett was as follows: The boilers to be designed for a test pressure which amounts to four-ninths of the bursting pressure, and the working pressure fixed at 90 lbs. below that pressure. The case of the boilers of the *Medea* and the *Medusa* were cited, and it was stated that the Admiralty Rule allowed a working pressure of 150 lbs. while Lloyd's rules allowed 123 lbs., making a difference of 26 per cent. I cannot reconcile these two statements, and I should like them to be cleared up. Without going further into this subject, all I can say is that, since the discussion of last year, I have not seen any reason to recommend to the Mercantile Marine of this country the desirability of reducing their scantlings. I think with a factor of safety of $4\frac{1}{2}$, such as is now used and has been working well for a great number of years, in the interests of safety and in the interest of the shipowner who wants his boiler to last as long as possible we should not make any further reduction in the factor.

Mr. R. Sennett (Vice-President): My Lord, I think this Institution, and the profession at large, are very much indebted to Mr. Scott for the generous manner in which he, at his own cost, has practically solved this question, which has interested the engineering world for many years. This paper of Mr. Scott's is, to a great extent, a supplement to a paper which I read last year. When I read my paper the statements I made had to be taken to a certain extent as matters of opinion. Certainly we had had boilers working, and working satisfactorily, of the dimensions and scantlings given, but, as Mr. Scott has stated, an ounce of practice is worth a pound of theory, and the experiment made by Mr. Scott has proved conclusively that no gradual increase of pressure will ever burst the shell of a steel boiler. Some of the gentlemen who have spoken on this subject, both this year and last, appear to have overlooked the fact that we are dealing solely with the scantlings of the shells of marine boilers and nothing else. It is a very old maxim that the strength of a chain is only the strength of the weakest link. In a marine boiler the weakest link is the combustion chamber or the furnaces, and while we have combustion chambers and furnaces of the dimensions that we are bound

to have, our contention is that any piling on of material on the shells of the boilers beyond the strength provided in the combustion chambers and furnaces is simply a waste of material, and tends to retard progress in working steam pressures and economy of coal. I said last year that in the course of my official career I have had to superintend the bursting of a very large number of marine boilers, by water pressure, after they had been for some years at work, and in no single instance was there the slightest sign of weakness in the shells of the boilers. Some of those boilers were made at a time before boilers were designed in the drawing office, and the details of the riveting were, as a rule, simply left to the foreman boilermaker; and although these boilers had a nominal factor of safety of five or six, the actual factor of safety in some cases, owing to badly-arranged rivet seams, was little more than three; yet those boilers wore out the whole of the inside, and with new furnaces and combustion chambers went off for four or five years' further service with the shells as they were. Last year I had to stand much adverse criticism, but, as my friend Mr. White pointed out, this came, not from people who had to make marine boilers, but mainly from those who had not the precise technical knowledge that the makers of marine boilers had. Mr. Parker said last year that if he had an actual factor of safety of three he would be perfectly satisfied. In this particular case the boiler shell, when tested to a pressure of considerably over three times the working pressure, showed not the slightest sign of weakness. Mr. Parker referred to cases in which the shells of boilers had burst owing to weakness. He was probably referring to certain land boilers, and in all these cases the bursting has doubtless been due to local weakness from corrosion, and does not in any way affect the question dealt with in Mr. Scott's paper.

Mr. W. Parker: Might I make a remark just in passing to clear that up? That is one of the elements which I contend a factor of safety should cover.

Mr. R. Sennett: That is just the point on which we differed last year. The element of corrosion should not, in my judgment, be met by an increase in the factor of safety, but by proper treatment, and, as Mr. White suggests, by a constant margin to meet that. The factor of safety ought not to be imposed to meet circumstances which can be overcome either by careful design or by proper inspection and treatment. So far as we know, this is the first occasion in which a boiler of the size in ordinary use has been subjected to such a test. The boiler shell which Mr. Scott has tested is in all its dimensions an actual copy of the gunboat boilers of the service. I am not quite able to follow Mr. Parker's figures respecting the working pressure that would be allowed for the test boiler by Lloyd's rules, and, although no doubt he has worked them out perfectly correctly, I am surprised to hear them. All I can say is, that the figures I gave for the *Medea's* boilers last year are absolutely correct, and that the rule which Mr. Parker quoted as to our Admiralty's practice is also correct. How the difference arises I am unable for the moment to say, but I can easily check it, and ascertain how it comes about. The boilers made by Mr. Scott for the gunboats are made under the same rules, and calculated on the same formulæ, as the boilers of the *Medea* and *Medusa*, quoted in my paper last year. We are all agreed as to the necessity of absolute safety for our boilers, and the only point on which there is any apparent discrepancy is that, under the present conditions of the rules that Mr. Parker works by, boilers of certain scantlings and certain riveting should have a factor of safety of four and a half or five, quite irrespective of inspection, quite irrespective of quality of the workmanship.

Mr. W. Parker: No.

Mr. R. Sennett: What I mean is that under Lloyd's rules, whatever the calculated bursting strength of the boiler is, the working pressure is obtained by dividing this by a certain factor called the factor of safety, and the boiler is tested by water pressure to twice this. On the other hand, we

say that the boiler should never be subjected under any conditions to a test beyond the elastic limit of the material; in fact, rather below that, and then after that we allow a working margin of 90 lbs. below the test pressure, and this is sufficient to give us absolute safety; and gives us also the power, as the working pressures of steam are increased, of carrying the increased pressure in an ordinary marine type of boiler without involving the use of plates of such increased thickness as would be practically unworkable.

Mr. Halpin (Visitor): Sir John Hay and gentlemen, I think there is one fact with regard to the design of boilers in this way which is to be borne in mind. The Institution of Mechanical Engineers, some years ago, made a number of experiments on this subject, and they came to the conclusion that the elastic limit of the material, and the elastic limit of the joint as a total structure, were practically different figures; and it was upon the elastic limit of the joint, as a finished joint, that they had to design the boiler.

Mr. H. MacColl (Member): Sir John Hay and gentlemen, I should like to call attention to one or two points which I think have not been mentioned in this discussion. In the first place, double-butt straps have shown results in this test which, so far as I am aware, have not been equalled by riveted strips in the testing machine. In experimental strips, the strength per square inch of the plate between the rivet-holes has always been less than that of the unpierced plate; while, in this case, the double butt strapped joint has resisted a stress equal to 93½ per cent. of the ultimate strength of the solid plate, and it is therefore probable that if the test could have been continued till the shell had burst, a pressure of about 660 lbs. would have been attained, and the full ultimate strength of the plate—about 62,000 lbs.—would have been reached. I lay particular stress upon this, because it indicates that the structure, as a whole, including the transverse joints, is capable of doing more work than a particular part taken in detail. The great support afforded by the transverse joint is also shown in Table V., where we find that under the greatest pressure attained, the extension in diameter at the transverse joint only amounted to about half that in the middle of the ring. In the second place, I would point out that, while the test shell is only 11 feet long, the actual shell which it is intended to represent is 16 ft. 9 in. long; the "free" plate between the transverse joints is, therefore, about 36 inches, or sixty times its own thickness in width in the test boiler; while it would be about 59 inches, or 100 thicknesses in width in the actual boiler. Now I think, with the much greater width of ring in the actual shell, it is doubtful whether it would have stood the same pressure before bursting. A third point which I have to mention is the behaviour of the flat ends. You will notice that these ends have bulged considerably—about 3⅝ inches. Now, I think if the longitudinal stays had not been reduced in diameter in the body, but made as they are in the Mercantile Marine, of uniform diameter throughout, there would have been less extension of the stays, and consequently less bulging of the ends. Therefore, in this respect the experiment does not show what would occur in a Mercantile Marine boiler. Perhaps Mr. Scott can give some explanation of Table IV., where at points 7, 8, 9, 10, and 11 the permanent bulge is greater at 450 lbs. than at 520 lbs. In conclusion, I would only add that Mr. Scott deserves the sincere thanks of every engineer for his liberality in making these experiments, and for his generosity in giving the full results of them to this Institution and to the world.

Mr. John Scott, C.B. (Member of Council): Sir John Hay and gentlemen, I will endeavour to reply in as few words as possible; but as rather a large number of points have been put to me, I possibly may have to ask your indulgence for a few minutes to do so. From what fell from Mr. Manuel, I must say that although this boiler was, from reasons of economy, which will be evident to all here, made comparatively small, nevertheless I took the actual size of a large number

of boilers working in the Navy, and many of the same type which I have made for the Merchant Service; I could not make experiments with boilers of 15 ft. or 16 ft. long, because one would have wanted a small fortune to have done so. However, although I was very glad to spend a few hundreds on this experiment, I was not prepared to expend some thousands, and, consequently, I could not extend the operation in the direction which Mr. Manuel would like. I should be very much delighted if his powerful Company, or the powerful Society which Mr. Parker represents, which are, in the public estimation, in possession of untold wealth, would render an obligation to the profession by making experiments on larger sizes, but, as a private individual, I do not feel called upon to do so. As to what Mr. Manuel said with reference to the size of this boiler, I would like to point out that the proportion of diameter to length—7 to 11—is not an unusual proportion in double-ended boilers of large sizes, and it could be taken in some sense as a miniature experiment, such as my friend Mr. White makes for the speed of his ships. On the question of whether heat strains are to be taken, so far as the shell is concerned, as varying very much from hydraulic strains done cold, I should like to say I do not believe, as far as the shell is concerned, that they do vary much. There may be differences from the temperature at the bottom of the boiler being different from that of the top. That is a difficulty which, by various modern means of circulating the water in the boiler, is being removed every day. I am aware in the Navy it has been remedied. By the use of feed heaters and other similar contrivances for promoting circulation, the temperature of the water at the bottom may be made the same as at the top. The same system is being introduced in the Mercantile Service, and when that shall have been universally adopted, I do not think we can take the strains, as far as the circular part of the shell is concerned, as being very different. However that may be, the efficiency of the cold test has always been taken as the standard in this country, and I could not proceed on any other lines. Mr. Manuel also was frightened that a boiler of this type, and made on these scantlings, would alter or commence to leak whenever it got heat into it at all. I have made a few boilers of this type for the Navy, and, as I said before, several for the Merchant Service, which are worked up to 160 lbs. or 170 lbs. pressure, and of the scantlings shown in the drawings, which have remained tight for a very long period. So far as the range of actual practice is concerned, I know that they will not leak if they are made properly. Mr. Manuel said that the Merchant Service wanted a tight boiler, and I, as a shipowner, want a tight boiler, and I have tried to make a tight boiler for myself. In many cases I tried to do it on the lines which are shown here, and I have not failed. I wish to point out in reference to what fell from some of the speakers, and I think one of the observations of Mr. Parker may be germane to the observation I now wish to make, that in these experiments, as I have stated in the paper, not a single rivet in the seams in this boiler has shown the slightest sign of failure. In the circumferential seams there is not a bad rivet now, after having had all the knocking about it has; not a single bad rivet to the eye, at any rate, and I believe they have all been tested with the hammer, and none appear to be started in the slightest degree; and it is for that reason that I have ventured to make the statement that I have done in the paper, that with modern good workmanship in boilers of the present day riveting can be depended on. With regard to the experiments which Mr. Parker has laid before us, of course I take exception, as Mr. Sennett has already done; I think that Mr. Parker might not have launched that at my head with regard to a boiler of actual size, because the statement made in my paper is that no boiler had been experimented upon that was of the size used in actual practice.

Mr. W. Parker: This is a locomotive boiler actually used now.

Mr. John Scott: We are a marine Institution, and we are talking of marine boilers in this room. I know perfectly well that locomotive boilers are made at that diameter, but we are talking of marine

boilers here; and bar steam launches, which in a discussion of this kind do not come into the sphere of observation, I think I am right in saying that there is no boiler in a vessel afloat of 4 feet in diameter, while there are many of 7, 7¼, and 8 feet, and I particularly guarded myself in the statement that I made in my paper, talking of marine boilers, because my paper is on the bursting of marine boilers—by saying that no experiment had hitherto been made on sizes in actual use. I know very well Mr. Parker's experiment, and we have our friend Mr. Cowper, an Associate of this Institution, who mentioned a case of a boiler of exactly the same diameter (4 feet) which he failed to burst; and one of the reasons why I made these experiments was this, that I considered the experiments which had hitherto been made not entirely satisfactory as regarded size used in actual practice. Now I know I should be entering on a subject open to very large discussion indeed if I went into the interesting points which Mr. Parker started last year, and put forward as one of the reasons why his Society imposes on the Merchant Service, and the Board of Trade (as far as they are concerned) imposes upon vessels of the Merchant Service which come under their cognisance, plates of heavy thickness, that they are doing it for the protection of the shipowner as regards the damage which may occur from use spread over a number of years caused by internal corrosion. What I should like to arrive at, and what I have endeavoured to arrive at in the present paper, is to show the point at which we may be safe as engineers; and I consider that that is the point to which any classification society, whether acting in the public interest, as the Board of Trade, or private individuals, such as Lloyd's Registry, should direct its attention—that they might prescribe to us the minimum that is safe. Everyone after that should be allowed to provide if he chooses for the long life of his boiler, if he thinks he is going to gain long life by adding thickness to it. That is the position I take up. It is very hard that those members of the shipowning profession who would like to make lighter boilers are not allowed to do so by Lloyd's simply because some of their engineers, or the heads of the Society, fancy that they are justified in imposing the larger thicknesses. I should like if those two societies would tell the profession where they think safety ends and where insurance begins. I have seen many old boilers broken up, as everybody who is a marine engineer has, and I know that the reflection of many of the owners after they have seen those thick plates broken up is, I wish to goodness we could put new insides to them. I have never seen except in very extraordinary cases which do occur now and then, and should be able to be checked by the able surveyors of the Board of Trade, who visit them every six months or a year, or by the able surveyors of Lloyd's, who visit them periodically, those special cases of corrosion, and they should be able to be checked by those gentlemen by internal visitation, if the societies do not appoint gentlemen who are too stout to get through the man-holes. There have been a great many other points put to me, but there is one point I should like to say a word upon. Mr. Parker called attention to a discrepancy in Mr. Sennett's paper of last year, as regards the difference in thickness which would arise in this case. I quite agree with Mr. Parker that the boiler which is shown on the wall, which I have experimented with, would be sanctioned by his Society for 135 pounds pressure, and the Board of Trade would sanction it for 130 pounds pressure. I have never seen the drawings of the *Medea* and the *Medusa*, but I think I can explain why there may be a discrepancy between the thickness in this case, and what was put by Mr. Sennett last year. The Admiralty specification, if my memory serves me right, provides for the use of 26 tons steel, with a limit upward. Well, I used in this case 27 tons steel. The Admiralty arrangement of butts on the boiler, if I remember right, go down to 75 per cent. of the percentage of the remaining plates, while I adopted in this case for the arrangement of butt straps 83½, and I fancy the *Medea* and *Medusa* boilers may have been calculated on those figures.

Mr. R. Sennett: In the case of the *Medea* and *Medusa* the figures I gave were based on the

worst possible case that might happen, and the minimum specified strength of the material was used in the calculation.

Mr. W. Parker: I merely wish to know this. Mr. Scott admits that this boiler would be passed by our Society for 135 pounds, and in the paper he states that it would be passed by the Admiralty for 145 pounds. That is a difference of 7½ per cent. Mr. Sennett states distinctly in his paper, read last year, that the *Medea's* boiler would be passed by his department for 155 pounds, and by our department for 123 lbs. only, which is a difference of 26 per cent. Why is there that discrepancy?

Mr. John Scott: I can only refer to the explanation I have given before. If any gentleman takes the trouble, which I cannot do just now, to work out the figures, he will see that the thickness of these plates for the Admiralty pressure of 145 might be reduced. I make this further observation in consequence of the clumsy method of measurement in this country only going by the thirty-second of an inch; it is quite possible that there may be a small percentage of difference between that and another thirty-second, which in this particular instance may make the difference. What I say is this, that by following out the basis laid down by Mr. Sennett last year in his paper it is clear that these boilers might possibly have been worked at a little higher pressure, and I think the results of the experiments would have justified that. Now, Mr. MacColl started a very important point, which I ventured to call attention to in the paper. Mr. Manuel referred to a number of experiments which he made on straight joints, pulling them in a hydraulic press. I am aware that Lloyd's Society, and I have no doubt the Board of Trade, have made a large number of those experiments. I always had the idea that those experiments, however carefully done, as far as boilers are concerned, gave false results, because they do not represent in a true manner the strains that came on the part that the experiment was intended to test, and I do not know any experiment made on large sizes which have ever been able to test the value of those straight made tests. I hope Mr. Parker will make a lot of experiments, even up to 15 ft. diameter shells, and see what the results are. I can only say that I have made experiments, and found that I got up to 93 per cent. I heard him state in this room that the ordinary test of those straight experiments came out at 10 per cent. below what it should have done in many cases. Here it has not come out at 10 per cent. below by a long way. I think that is one of the elements, and would be a good one in coming to a conclusion, which I venture to do in the concluding words of my paper, that there has been reason shown by those experiments which have been detailed to you to-night, though probably in a very imperfect manner, why classification societies may permit those who wish to do so to reduce the scantlings of the shells of their boilers.

Mr. R. Sennett: With reference to the small difference in figures mentioned by Mr. Parker between the boiler referred to in Mr. Scott's paper to-night and my paper last year, I am quite unable at this moment to say exactly how it arises, but I propose, with the sanction of the Council, to add a note to my remarks explaining the matter.—(The following is the note referred to:—The explanation of the apparent discrepancy in the figures pointed out by Mr. Parker is practically that given by Mr. Scott in his reply. The specified scantlings of the shell plates are based on an assumed minimum tensile strength of 26 tons and an efficiency of joint of 75 per cent. In the actual boiler, the minimum strength was 27 tons and the efficiency of joint 83·7 per cent. The thickness of plate was also slightly greater than given by the calculation, and, in point of fact, the shell plates of these gunboat boilers are thick enough by the Admiralty rule for a working pressure of 170 pounds per square inch instead of 145, and the experiments clearly show that with this working pressure there would be an ample margin of safety. The figures given for the *Medea* in my paper of last year were exactly in accordance with the Admiralty formula.)

The Chairman: I am sure that the thanks of the meeting are due to Mr. Scott for the interesting paper which he has given to us, and for the very interesting discussion which has been elicited by it.

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THE ETHER-PRESSURE THEORY OF THERMODYNAMICS APPLIED TO STEAM.

By J. Macfarlane Gray, Esq., Member of Council.

[Read at the Thirtieth Session of the Institute of Naval Architects, April 11th, 1889; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

In 1880 and again in 1885 I read papers before this Institution upon the same subject with which I now deal. In the 1885 paper I told you that I could not then reconcile the ether-pressure theory and the Second Law of Thermodynamics with the then universally accepted view of what non-perfect gas is.

Since that date I have discovered that that view of gas is what has to be modified, and then the Second Law stands in perfect harmony with the ether-pressure theory. I cannot in this paper give all the details of the investigation, and as I am arranging to read papers on the same subject before the Institution of Civil Engineers and also before the Institution of Mechanical Engineers, I have thought it best to give in the present paper only a popular introduction to the ether-pressure theory, and an account of what the form of the thetaphi diagram now is. Those who are interested in the mathematics of the subject can afterwards see those other papers, or they may examine the originals in my possession now.

As my first paper on this subject was, at my request, not included in the Transactions, it will be necessary that I should now run over the introduction I then gave, only altering it to conform with my present views.

Ether-pressure is an idea as old as Greek science, and Newton believed it to be the cause of gravitation, but he did not publish any theory about it, "because he was not able from experiment and observation to give a satisfactory account of this medium, and of the manner of its operation in producing the chief phenomena of nature."

Since the close of the terrestrial chapter of Newton's life, the modern theory of thermodynamics, the atomic theory of chemistry, the kinetic theory of gases, the

science of electricity and magnetism, the undulatory theory of light, the spectroscope, and the telephone have all been won by human thought. We are, therefore, to-day, in a much better position for theorising on physical phenomena than Newton was. The author believes that if Newton had, with these advantages, attempted the problem which has taken himself so many years, he would have solved it completely in as many days.

The view according to which the investigations referred to in this paper have been prosecuted is, that every physical phenomenon is the immediate result of the pressure of an invisible and impalpable universal molecular ether upon the external surfaces of the molecules of ordinary matter.

The pressure of the ether must be many millions of tons upon the square inch. To produce gravitation, Maxwell tells us that "if the ether is molecular the grouping of the molecules must remain of the same type, the configuration of the groups being only slightly altered during the motion."

In my 1880 paper I gave a long quotation from "Locke's Essay on the Human Understanding," in which he refutes the ether-pressure theory, as then understood, on the ground that although such a pressure might prevent two bodies from being pulled apart in a direction normal to their surface of contact, it could not prevent them from being slid the one upon the other, and so separated in a direction parallel to that surface. I did not know then that Locke and Newton were intimate friends : I know that now, and I therefore now regard that quotation as being probably not altogether Locke's objection to the ether pressure theory, but really the only published statement there is of Newton's difficulty.

The difficulty as there stated is entirely overcome when the ether is considered to consist of separate particles of matter, each particle very much smaller than the atoms of the substances known to the chemist but, however small, still in magnitude bearing a significant ratio to them.

In elementary thermodynamics it is proved that if a body is in the form of a gas, its particles flying to and fro in all directions, then, if the magnitude of the particles be neglected, that is, if they be regarded as mathematical points, but possessing impenetrability and the inertia property which characterises matter as different from space, the energy of the to-and-fro motion must be numerically one and a half times the arithmetical product of the pressure by the volume. Such inertia points must, therefore, have each on the average a play space numerically equal to two-thirds of the quotient of its energy divided by the pressure per unit of area, or

$$v = \frac{2}{3}\frac{\mathrm{E}}{p},$$

Call the particles of the ether *ethids*, to distinguish them from the atoms and molecules of ordinary matter. Let the ethids be considered as minute spherules. The same relation $v = \frac{2}{3}\frac{\mathrm{E}}{p}$ must hold good for the ethids as for the molecules of a gas. What is the effect of the spherule magnitude in modifying the expression $v = \frac{2}{3}\frac{\mathrm{E}}{p}$. It is evident that the volume denoted by v must be the dynamic volume only, namely, that traversed by the centres of the ethids.

To make explanation simpler, let the molecule of a gas be regarded as having the form of a rectangular prism, say it is a minute brick of matter. At first let it be thought that the brick is battered by the ethids always at the same spots, and let there be at each of these spots a hollow, so that the ethids when in collision with it have their centres in the plane of the rectangular surface of the brick. The $v = \frac{2}{3}\frac{\mathrm{E}}{p}$ formula refers to the space traversed by the centres of the ethids, so that it is evident that the effective volume of the brick in the ether is that which includes these cups. When two of these cupped bricks are brought together, the effective volume of the pair will be just the sum of their volumes singly. If the cups were planed off the two sides which are to be brought into contact, the effective volume of the pair in contact would be then that amount less than the sum of their volumes singly.

If, however, the cups were planed off all the sides of the bricks, their effective volumes singly would be just the same as before, because the course of impact of each ethid would terminate at the same point as before. And when the two are in contact at one pair of sides, the total effective volume is just as much reduced as it was in the first case. The total effective volume of two molecules of matter in the ether is, therefore, less when they lie in contact than when they are apart.

In my first paper I gave the names for these volume differences, to which I still adhere. The point at which the centre of an ethid is when in contact with a molecule is called the meta, meaning, *turning point*. Meta was the name of the turning post in the Roman circus, and in that sense I have elsewhere shown that it stands in the naval architect's word, metacentre.

The surface which would contain all the metas is called the metasurface. It is at a distance from the surface of the molecule equal to the radius of an ethid.

The space between the metasurface and the matter-surface of the molecule is called the metafilm of the molecule.

The metavolume of a molecule is the volume including the metafilm.

The matter volume of a molecule is the volume exclusive of the metafilm.

The pressure of the ether is the immediate cause of gravitation. From that we can arrive at a measure of what the differences of ether pressure must be as a minimum. How much greater than that minimum they may be cannot at present be determined.

We know that matter can be at least as dense as platinum. Say that a bar of platinum 7,926 miles in length, the earth's equatorial diameter, and one inch square in section, is going round the sun on the earth's orbit. The effective ether appulsion which produces the curvature of its path is 104 tons upon the square inch. The calculation is

$$\left(\frac{6{\cdot}2832 \times 5280}{365{\cdot}25 \times 86400}\right) \frac{92{,}000{,}000 \times 7926 \times 1342}{32{\cdot}2 \times 144 \times 2240} = 104{\cdot}12.$$

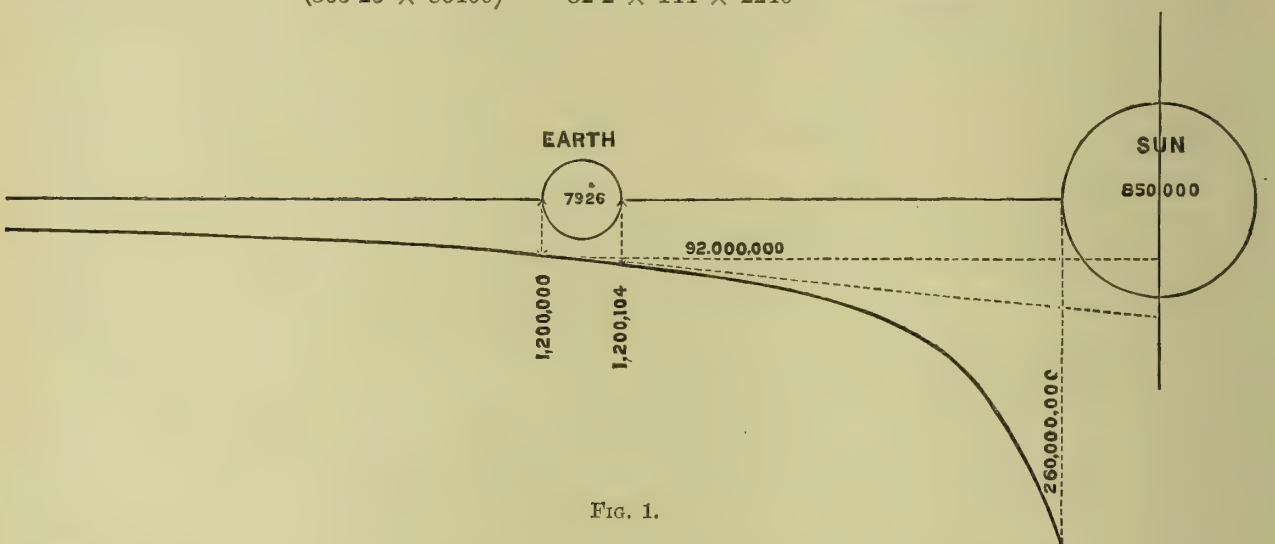


Fig. 1.

The 92,000,000 is the radius of the orbit, 1342 is the weight of a cubic foot of platinum. The ether pressure is diminished in the neighbourhood of any body consisting of an aggregation of ethids, and that reduction is directly proportional to the mass and inversely proportional to the distance from the mean centre of the mass. This is what is usually called "potential." It will be here called the sub-pressure of the ether. A radial diagram of the sub-pressure is the common hyperbolic curve. It is the slope of the sub-pressure which produces appulsion. In Fig. 1, from the curve downwards is the ether-pressure. Between the curve and the straight line is represented the reduction of pressure. The line of zero pressure, to the same scale, is a great distance below the bottom of the page, probably such a distance that the sub-pressure shown on the diagram is in comparison therewith quite insignificant.

There is no such action in nature as that which is implied in the word attraction. Newton asserted that there was not any such force. The difference between $\frac{1}{\rho - \frac{1}{2}}$ and $\frac{1}{\rho + \frac{1}{2}}$ is $\frac{1}{\rho^2}$ when ρ is great. That makes appulsion to vary inversely as the square

of the distance. If the slope of an element of the hyperbolic curve is continued to the vertical axis, the line will rise just what the ordinate was where the slope was fixed. We have a rise of 104 tons on 7,926 miles, and the sub-pressure at the earth, that is the ordinate where the slope is taken, must therefore be

$$\frac{104{\cdot}12 \times 92{,}000{,}000}{7926} = 1{,}200{,}000,$$

that is, 1 million tons on the square inch.

The solar sub-pressure at the surface of the sun, its radius being 425,000 miles, must be

$$\frac{1{,}200{,}000 \times 92{,}000{,}000}{425{,}000} = 261{,}630{,}000,$$

that is, 260 million tons on every square inch, and that is to the total pressure of the ether no more than a wave trough to the depth of the Atlantic.

As the ether pervades the molecular interstices of all bodies, the pressure on any surface of any molecule is nearly balanced by the pressure on the opposite surface, and it is only the difference of these two that we can be experimentally cognisant of. On the earth's surface at the equator, bodies are subjected to a pressure which is over one hundred tons per square inch greater at midnight than at midday.

What has now been calculated is the solar sub-pressure. Similarly around the earth, and extending out to stellar space, there is also a terrestrial sub-pressure. A bar of platinum, 144 ft. in length and one square in. in section, weighs 1,342 lbs. at the earth's surface. If placed vertically, the ether pressure must be 1,342 lbs. per square inch greater at the top end than at the bottom. The slope of the terrestrial sub-pressure is therefore

$$\frac{1342}{2240} \times \frac{5280}{144} = 21{\cdot}967$$

say, 22 tons per square inch per mile. This, multiplied by 3,956, the earth's mean radius in miles, gives say 87,000 tons per square inch, as the terrestrial sub-pressure of the ether at the surface of the earth. The sub-pressures of different bodies are superposed without being in the least degree modified one by another. Every atom as it was formed by aggregation of ethids, produced its own cosmical sub-pressure, by the vacation of their play-spaces and by the reduction of metafilm by the contact of surfaces in it. As atoms became molecules, and molecules concreted into blocks, the sub-pressures of each particle were added together, until, as in the solar sub-pressure, it amounted to hundreds of millions of tons on the square inch. These rough calculations are given now in order to make the subject less hazy than when mere generalisations are hesitatingly mentioned. These are, however, merely minimum limits ; for, just in the proportion that absolutely solid matter would be of greater specific gravity than platinum, so must these differences of ether pressures be all increased. In approaching

the Ultimate, we must never forget that there is really "no high, no low, no great, no small" but in our own thinking, and therefore, pressures of millions, billions, or even trillions of tons upon the square inch on every face of every atom of matter is just as likely as not, until the contrary is ascertained to be true; the most stupendous forces dealt with by man, and likewise those so much greater revealed to us in physical astronomy, may be, standing out in this ether pressure no more than wavelets upon the surface of a fathomless ocean, whose interweaving ripples make up man's phenomenal universe.

Having, from what is observed in gravitation, obtained a proof of the enormous magnitude of the pressure with which Nature works everywhere, we ought to be prepared to find that in the aggregation of atoms the magnitude of cancelled metafilm may bring about the realisation of an enormous expression of ether energy. It is also obvious that when a multitude of similarly aggregated atoms is brought into contact with another multitude of different atoms, all arranged similarly in a different way, if

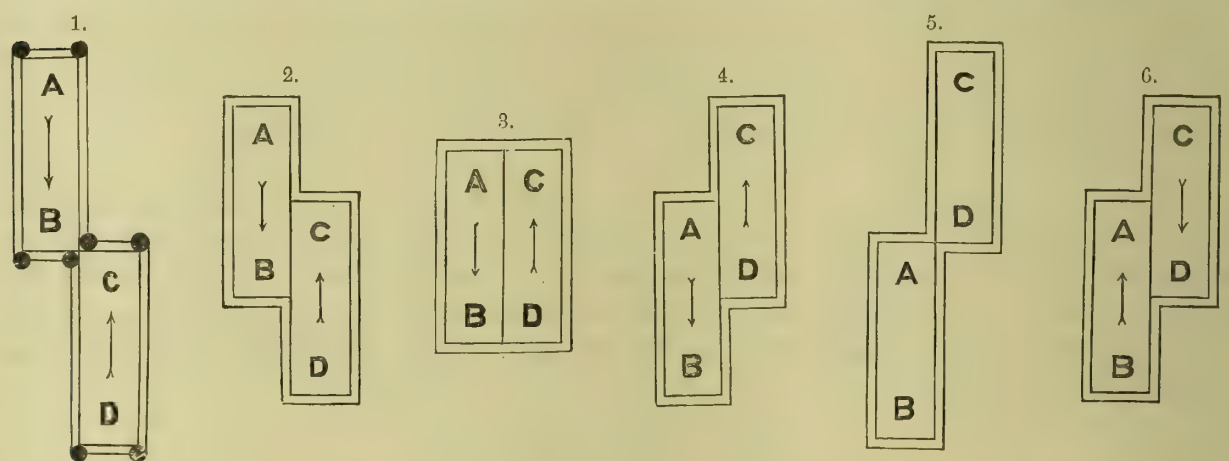


Fig. 2.

these are violently shaken together, the two sets of molecules may exchange mates, if, by doing so, the metavolume of the whole mass can be thereby reduced. The atoms may have many different forms, and the smallest atom may not have the smallest faces. This is the explanation of chemical affinity. Minimum metafilm is the goal in every chemical action.

In the boiler furnace the oxygen and carbon atoms go together with important diminution of metavolume, and the energy of the ether expansion is then in the to-and-fro motion of the atoms in the molecule. In considering this to-and-fro motion of the atoms, it will be simpler to adhere to the brick form of atom; the same reasoning will apply to many other forms. The action is illustrated in the accompanying diagram as for maximum movement.

In No. 1 the bricks A B and C D are just touching at the B C corners, and their total metavolume is almost a maximum. Let the pair of bricks be then at rest except relatively. They are being battered on all sides. They, therefore, cannot remain in that position, for the effective area of the D end is greater than that of the C end by the area of the cross-section of the metafilm sheet in the B side of C D, and similarly for the ends A and B. The pressure of the ether on an area equal to those cross-sections of metafilm propels the bricks together. Observe that the section of the metafilm × the travel of each upon the other, is precisely the volume of metafilm cancelled upon each brick. They pass through phase 2 with great accelerity, and in phase 3 their velocity is a maximum. The region of the ether has expanded by as much as the metavolume has diminished, and the work done by the ether in its expansion is now in the relative energy of the bricks. That impetus carries them on through phase 4 now with great decelerity, for they are now expending their energy in compressing the ether as their metavolume increases. In phase 5 they have again attained their maximum metavolume, and are relatively at rest. In phase 6 they are again approaching in the opposite direction. The ethids are supposed to be grouped in a certain fashion, so that a compression of the ether at any place provokes an increased local pressure there as if it were a solid body. The effective force, therefore, increases with the compression, and in direct proportion to it in such an example as that now described. The reciprocating motion would, therefore, be isochronous, and the author suggests that this is the condition of glowing matter, as in the sun's photosphere or in flame anywhere. The length of travel may, however, be very small.

Isochronous vibration sets up that palpitation of the ether which is called radiant heat, and at every stroke of the reciprocation less work is done upon the atoms by the ether than was in the preceding stroke done by the atoms upon the ether. The radiant state of gas is that in which the atoms of the molecules are relatively in motion. At a lower temperature the atoms are not in relative motion, and then the gas is not radiant, but it can by impact render any solid containing it radiant. That is, the molecules of solid bodies and liquids are in continual reciprocating motion upon each other, as the two bricks which have just been described, but the length of travel is much less.

This theory explains the cohesion of solids. The extension of a body within its elastic limit is a minute sliding upon each other of all the molecules in the body in the direction of the pull, and the work done upon the body in extending it is really spent upon the ether by increase of metafilm accompanying the extension. It is the same in compression, it is still an increase of metafilm and metavolume.

Where does latent heat hide? When boiling water is evaporated at atmospheric pressure, say, in an open vessel, the work done upon it over and above the boiling heat

is what is equivalent to lifting the water 142 miles high. The heat due to the steam as a gas is about 38 miles of that height, and the latent heat proper, or that which is still hidden, is the other 104 miles, and there is perhaps 84 miles more for all the heat which was in the water before evaporation. Say 226 miles altogether. All the work of the last two, 188 miles of lift, is invested in the compression of the ether by the increase of metafilm, when the water molecules are parted from their liquid contact. The increase of exposed molecular surface when one rain-drop only is evaporated must amount to many square feet of area, and in the change of state there must be the same amount of creation of metafilm, and consequently the work of compression of the ether. When, in condensation, these particles come together again, the previously hidden energy reappears as heat.

According to the notion of metafilm which has now been explained, the energy expended in raising the temperature of a solid or a liquid from absolute zero, is accounted for by the continually increasing amplitude of the relative motion of its contiguous molecules, which, sliding upon each other reciprocatingly, thereby increase the mean molecular metavolume of the substance, and so compress the ether. When, at last, the extent of reciprocating travel has increased so much that the molecules part company, the initial step in evaporation has taken place ; but the communication of the constitutional energy of vapour at that temperature has yet to be effected. What that constitutional energy of gas is will now be considered.

It has often been explained, in works on thermodynamics, how it is that the energy of translation in gas is one and a half times its $p\ v$. This is a beautiful flower, which, I think, every engineer should carry in a mental buttonhole. From the following explanation, it may be obtained, perhaps more easily than from other statements of the reasoning given in books.

The rate per second per square inch of surface at which momentum normal to that surface is changed, is the pressure upon that surface per unit area in poundals. Dividing by $g = 32{\cdot}2$ gives that pressure in pounds per square inch.

If in a gas the particles and their motions are uniformly distributed throughout the volume, whether it be uniform order or uniform confusion, the components of the motions in any volume will be equally distributed in any three rectangular directions.

Take the components of the motions towards any element of surface to be considered, and in these components let there be always a mass m per unit volume moving with the component velocity u_1 normal to that element of surface. The component momentum of that mass is always $m\ u_1$, and if the particles are without magnitude, this mass m will be delivered upon the surface at the rate of u times per second per unit area. If the particles had magnitude, the rate of arrival of momentum would be greater, because then they would not have to travel so far before they had

arrived and had to be reversed. The rate at which that momentum approaches the surface is therefore $m\,u_1^2$, regarding the particles as without magnitude. This momentum is all reversed in impact. As the difference between receiving a sovereign and giving one away is two sovereigns, so the change of momentum of these particles in impact is $2\,m\,u_1^2$ per second per square inch of surface. When this is calculated similarly for all the lots of particles separately, and the sum of all the various quantities of the form $m\,u_1^2$ is found and divided by the total mass per unit volume w, let the quotient be written $= \bar{u}_0^2$. This is called the mean square component velocity, and $\bar{u}_0$ is the velocity of mean square component. The pressure then, according to the previous statement, is—

$$p = 2\,w\,\bar{u}_0^2, \text{ in poundals per square inch.}$$

Now, for each of the quantities $m\,u_1^2$ normal to the surface considered there will be an equal m with equal u_1^2 normal to each of the six surfaces of the cube. The sum of the squares of the actual velocities is equal to the sum of the squares of the component velocities for each m making up the total mass w per unit volume. Write now for the sum of the masses each multiplied by the square of its actual velocity—

$$w\,\bar{u}^2 = 6\,w\,\bar{u}_0^2,$$

$\bar{u}^2$ is called the mean square velocity, and $\bar{u}$ is called the velocity of mean squares.

Since

$$p = 2\,w\,\bar{u}_0^2$$

we have

$$3\,p = 6\,w\,\bar{u}_0^2 = w\,\bar{u}^2$$

or, pressure in poundals

$$= p = \frac{w\,\bar{u}^2}{3}$$

or, pressure in pounds per square inch

$$= p = \frac{w\,\bar{u}^2}{3\,g}$$

The w will increase along with v as the volume is taken greater, therefore—

$$p\,v = \frac{w\,\bar{u}^2}{3\,g}$$

Now, energy

$$= \mathrm{E} = \frac{w\,\bar{u}^2}{2\,g}$$

Therefore—

$$\mathrm{E} = \frac{3}{2}\,p\,v$$

In this statement there has been no restriction about motions, except impartial distribution, and the particles have been considered to be mathematical points. If the ether is not continuous matter, this relation of $p\,v$ to energy must apply also to it

when the magnitude of the ethids is neglected. In any vessel containing gas or steam, the gas would consist of a multitude of molecules fairly distributed through a much greater multitude of ethids, and the actual pressure would be one common to ethids and molecules. The apparent or effective pressure would, however, be the excess of that common pressure above the external pressure. The actual $p\,v$ of gas and ether would be two-thirds of the motion energy of both ethids and molecules. The mean play-space of any one ethid, or any one molecule, would be also determined by the relation $v = \frac{2}{3}\frac{\mathrm{E}}{p}$, in which E would be the mean energy of that particle, and v its mean play-space.

Although the play-spaces of each are interspersed throughout the whole capacity of the vessel containing them, there is never any confounding of play-spaces. We may, therefore, to simplify reasoning, imagine, without ignoring any dynamical necessity, that all the gas molecules are collected at one end of a cylinder and all the ethids at the other, and we may picture to ourselves that there is a mathematical piston between

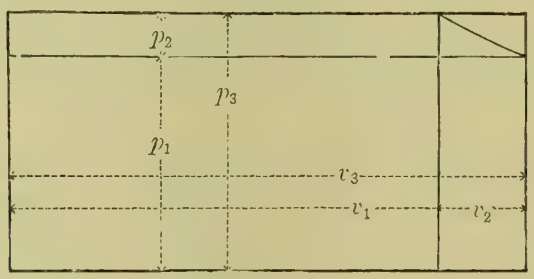


Fig. 3

the two, an impenetrable movable mathematical surface. Begin with the molecules at absolute zero of temperature: they are then without motion, and the space dynamically occupied by them is nil. Let energy now be communicated to the molecules: the gas assumes a dynamic volume, and the ether is compressed. I am now departing from the rationale of this action given in my 1880 paper. I regard the ether now as not bodily displaced, but only compressed in the cylinder. Whatever be the modified velocity of the inner ethids, that is exchanged in impact for the velocity of the external ethids at the inner surface of the cylinder, and the modified velocity passes on at lightning speed into free space. The velocity of the inner ethids is, therefore, maintained at the normal velocity of the external ethids, in any state of compression of play-spaces, that is, they are compressed with constant energy, and therefore with the $p\,v$, for each ethid a constant. The mathematical piston will have moved during the compression, and the indicator curve of compression will be that for constant $p\,v$, that is, a common hyperbola.

The $p\,v$ of the ethids, $p_3\,v_3$, is still the same as before, $p_1\,v_1$. The total $p\,v$ is increased by what is now the $p\,v$ of the molecules $p_3\,v_2$. Anyone not knowing that the ether is there would think that this $p_3\,v_2$ is the only $p\,v$ in the cylinder, and they would write it as $p_2\,v_1$. The p_2 is the apparent pressure, or the excess above the external pressure. Now, what is the amount of constitutional energy required by the gas molecules to bring them from zero temperature to their condition $p_3\,v_2$? The actual or motion energy of the molecules is $\frac{3}{2}\,p_3\,v_2$ and the work of compression is, say $\left(p_1 + \frac{p_2}{2}\right)\,v_2$. As p_2 is insensibly minute in comparison with p_1 it will lead to only an insensibly minute error if we regard this as equal to $p_3\,v_2$. The sum of these, actual energy and compressive energy, is therefore $\frac{5}{2}\,p_3\,v_2$. Now, although this process has been described as one of change of volume, it has really all been accomplished in a cylinder at constant volume, the ethids and the molecules uniformly distributed and interspersed. This is, therefore, the energy required for increase of temperature at constant volume, or for the increase of $p\,v$ under any condition, $2\frac{1}{2}$ times the increase of $p\,v$.

When the volume of gas is increased at constant pressure there must be external work done equal to that increase of $p\,v$. In that case the statement of energy is as follows :—

Increase of motion energy	$= 1\frac{1}{2}$
Increase of molecular play-space	$= 1$
External work	$= 1$
Total energy of increase	$= 3\frac{1}{2}$ times the increase of $p\,v$.

Therefore, the ratio of energy required for increase of $p\,v$ at constant pressure to that required for increase of $p\,v$ at constant volume is $3\frac{1}{2} \div 2\frac{1}{2} = 1{\cdot}4$. That is the number which is generally denoted by the Greek letter γ in English works on thermodynamics. It is generally given as $\gamma = 1{\cdot}408$. This figure is that obtained from certain experiments on the velocity of sound in air, for which the formula—

$$U^2 = g\,\gamma\,v\,p$$

should hold. In this formula v is the volume of one pound of air in cubic feet and p is the pressure in pounds per square foot. More recent experiments give $1{\cdot}402$, a remarkably close agreement of experimental results with the preceding theoretical deduction. In a paper on Regnault's Determination of the Specific Heat of Steam, read before the Physical Society on February 25, 1882, I have shown that this ratio is also fairly corroborated by Regnault's experiments on steam.

I have now to apply these deductions, that the heat of segregation is a constant quantity at all temperatures, that the specific heat of a gas at constant volume is $2\frac{1}{2}$ times its change of $p\,v$, and that the specific heat at constant pressure is $3\frac{1}{2}$ times its

change of $p\ v$. I have here used the word heat as interchangeable with the word energy. It is convenient to do so in such a paper as this. When the unit of volume is taken to be as many of the ordinary units of volume as is expressed by the number denoting the mechanical equivalent of heat, energy and heat are expressed by the same numbers, and the letter J elsewhere generally repeating itself in all formulæ disappears altogether. I follow that plan now. According to this convention, unit $p\ v$ is the mechanical equivalent of the unit of heat.

As this paper is already much too long, I cannot do more than merely describe what is now the form of the thetaphi diagram.

On the thetaphi diagram (Plate XXX.) the area is heat or energy, the vertical ordinate is absolute temperature, and the horizontal dimension is called entropy. This is a word introduced by Clausius to mean "transformationability." I think it a very pretty word, but I would give it another interpretation. Entropy is length on a diagram on which the vertical ordinate is absolute temperature, and the area is energy, in heat units. Regarding the diagram as a heat chart, the idea of entropy is that of longitude only.

On the diagram now exhibited, the temperature is expressed in Centigrade degrees, counting from absolute zero. I think that is how temperature ought to be always stated. The primary curve to the left of $\mathcal{A}$ is the thetaphi graph for ice, the specific heat being taken as constant, and $= 0{\cdot}5$. The area between this curve and the zero base line up to the vertical for any temperature $= \frac{\theta}{2}$, where θ is the temperature. The $\mathcal{A}$ curve is, therefore, a logarithmic curve. A logarithmic curve is one in which the vertical ordinate at any point is a constant multiple of the area from the origin up to that point. When the ordinate is numerically equal to the area, the horizontal dimension or entropy is the hyperbolic logarithm of the height. The entropy of any point in $\mathcal{A}$, is half the hyperbolic logarithm of the temperature, counting from some point where the entropy is, for convenience, said to be nil. This is like choosing a first meridian; it does not, in principle, matter where it is. Zero entropy is most conveniently placed at the point where liquid water has the temperature of melting ice, that is, at A 273. From $\mathcal{A}$ 273 to A 273 is $= {\cdot}293$ and $273 \times {\cdot}293 = 80$, the heat of liquefaction. The unit of heat I adopt is the specific $p\ v$ of hydrogen gas, that is, 1386 ft. pounds for the Centigrade scale, or 770 ft. pounds for the Fahrenheit scale. The specific heat of water is not accurately known, but from the recent experiments of Rowland, at Baltimore, United States, I am led to adopt $1{\cdot}0106$ as the specific heat of water, and, for the present, to assume that that is constant, for the mean specific heat, up to any temperature, when the water is heated from maximum density under the

pressure due to steam at the given temperature. The primary curve or thetaphi graph A is, therefore, set out according to the equation—

$$\theta\, d\,\phi = 1{\cdot}0106\, d\,\theta, \quad \text{or} \quad \text{O A} = \epsilon \log \frac{\theta}{273}$$

that is, so that the area swept by the vertical ordinate is always 1·0106 times the change of temperature. The new unit of heat is a great advantage in the arithmetic of thermodynamics, and it is almost identical with what has hitherto been used, 772 ft. pounds, for Fahrenheit scale. The letter ϵ stands for 2·30258509, and log then means the common logarithm.

The curve B is that of the loci of points defining equal areas equal to the heat of segregation, or, in less formal language, the splitting heat. If, from any point in B, a horizontal line be drawn to A and a vertical line to Z, then these two lines, the base line and the broken curve $\mathcal{A}$ A will contain an area equal to the constant splitting heat, that is, 501·4 heat units in addition to the area to the left of zero entropy.

For any substance in the state of gas—

$$\frac{2}{m}\,\theta = p\,\{v + f\,(\theta)\}$$

I cannot get in the explanation of this to-night, it is too long a story. At the temperature of melting ice, steam is very nearly in the condition in which

$$p\,v = \frac{2}{m}\,\theta$$

Here m is the molecular weight of the substance. At any other temperature the $p\ v$ of the saturated steam is $\frac{2}{m}\,x\,\theta$, in which x is always less than unity. In the diagram B G is $\frac{7}{m}$, and in my former papers I set off the saturation curve E so that A E $= x$. A G in accordance with the common belief that saturated steam is not perfect gas, that is, that the gasefication has not been carried out to the utmost extent. By a process of mathematical reasoning, I have been led to see that saturated vapour is always perfect gas. The whole of the splitting heat has been expended upon it, and its molecules are all single molecules. The E graph is therefore placed so that at any temperature—

$$\text{B E} = x\ .\ \text{B G} = \frac{7}{m}\,x.$$

The F curve is placed so that—

$$\text{E G} = 1{\cdot}4\ \text{E F}.$$

The curve H is a reference curve such that—

$$\text{A H} = \frac{2}{m}\,\frac{\theta\, d\, p}{p\, d\, \theta} = \frac{\text{A E}}{x}$$

The Second Law of Thermodynamics requires that upon this diagram every point

shall have a characteristic state, so that passing from any point by any graph, and returning to the same point, the initial condition of the substance will again be arrived at. Or, the condition of the substance at any point is the same, by whatever path it has been reached.

When steam at 273° is increased in temperature, maintaining the pressure constant its thetaphi graph is the curve P. When at the temperature θ, let it be compressed at constant temperature. Its compression curve on a peevee diagram is the common hyperbola. While the temperature is constant, the equation

$$\frac{2}{m}\theta = p\,(v + c)$$

holds good. Here a constant, c, is substituted for what was before written a function of the temperature. The c, when at the low initial pressure, was quite insignificant in comparison with v. It was, in fact, only the ·0003 part of v. The compression up to the pressure of saturation at θ is that of constant $p\,(v + c)$; the c part is outside the cylinder. As the volume diminishes, the c becomes an important magnitude in comparison with the v. Up to saturation there is no liquefaction.

The compression can be ideally divided into two parts: say a series of pairs of steps, each consisting of, one, an increase of p with x constant, and one a reduction of $p\,v$ with p constant; these steps, however, occur simultaneously and not consecutively. The work $p\,.\,d\,v$ for each of the sets of steps can be legitimately estimated separately.

As these steps are both compression, I ask you to permit me to call the one set appression, or the increase of pressure *per se*, and the other collapsing, being the reduction of volume without change of pressure. I shall employ the word compression to denote the combined action.

Between p_0 and p at constant temperature, writing Δ "for the difference of," the respective energy quantities will be—

Writing $z = 1 - x$

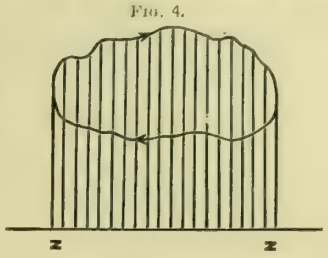
Appression	$\frac{2}{m}\theta\epsilon \log\frac{p}{p_0} - \frac{2}{m}\theta\,\Delta\,z$
Collapsing	$\frac{2}{m}\theta\,\Delta\,z$
Heat abandoned	$\frac{5}{m}\theta\,\Delta\,z.$

At any position intermediate we have these equal to Pg, $g\,f$, and $f\,e$ respectively, and when the state of saturation is arrived at, they are P G, G F, F E.

When the appression point crosses G, then liquefaction commences. Any other arrangement would involve the possibility of there being more than one condition of the substance for the same point on a thetaphi diagram, and that is inconsistent

with the Second Law of Thermodynamics. The Second Law is that, on a thetaphi diagram, for every point there is a characteristic state. The work done over any right-handed closed graph is, therefore, that represented by the area enclosed by it. If the enclosed area (Fig. 4) be divided up into vertical bands by straight lines extending to the base line, it will be seen that the work area is that between the two intersected temperatures, the heat expended on that element is that length of the band which is denoted by the higher temperature, and the heat thrown away is that length of the band denoted by the lower temperature, and, therefore, the work efficiency of that band is the fraction which the difference of the two temperatures is of the higher temperature. This is what is known as Carnot's Function.

Fig. 4.



In the thetaphi diagram the splitting heat is made a constant, and the specific heat is that deduced from $\gamma = 1{\cdot}4$. The specific $p\ v$ of hydrogen gas is 1,386 foot pounds per Centigrade degree, or one heat unit in the measure used in this paper. The specific $p\ \{v + f(\theta)\}$ for any gas is $\frac{2}{m}$ heat units, where m is the molecular weight of the substance. With hydrogen $m = 2$, therefore its $\frac{2}{m}$ = unity. In steam, m is generally taken = 18, and for all practical purposes that is near enough, but in this paper I have used the more accurate number 17·96. The specific heat of steam employed by me is, therefore—

$\frac{5}{m}$, at constant volume = ·27840

$\frac{7}{m}$, at constant pressure = ·38976

$\frac{2}{m}$, specific $p\ \{v + f(\theta)\}$ = ·11136

Heat of segregation .... = 501·4 + heat at 273°, liquid.

It will be observed that I employ the term, heat unit, as a measure of energy. Heat as a phenomenon is the sensible aspect of molecular motion; heat as a quantity is the constitutional energy of molecular motion. Part of that energy is active in the molar energy of the individual molecules, and part of it is invested in the ether, for metafilm and play-space, and, therefore, I call it altogether constitutional energy.

According to these numerical constants, the thetaphi diagram has been constructed, and the test of the soundness of these principles is that without introducing any arbitrary constant whatever, the ratio of steam pressures at different temperatures has been worked out according to it for the whole range of temperatures experimented on by Regnault, and the results obtained differ less from the experimental results than

the pressures calculated by Regnault's most elaborate formulæ do. The latent heat also agrees with Regnault's experimental results. That section of my work is reserved for the paper for the Institution of Mechanical Engineers.

The principal equations in that investigation are

$$C + \frac{2}{m}z - \frac{2\epsilon}{m}\log z = \frac{777{\cdot}3}{\theta} + 1{\cdot}0106\,\epsilon\log\theta,$$

and

$$\log p = [0{\cdot}5910552]\,\overline{F\,G} + 25{\cdot}33779 - [0{\cdot}7462505]\log\theta - [3{\cdot}4816439]\frac{1}{\theta}.$$

From the first the value of $F\,G = \frac{2}{m}z$ is found for any given temperature, and then the second gives the pressure in millimetres of mercury. The numbers within brackets are the logarithms of the co-efficients. The actual calculations are on the table in the room, and may be inspected.

Having now cleared up the difficulty about the Second Law, the thetaphi diagram may be with confidence employed in the solution of all problems in thermodynamics. In the paper on Steam Engine Economy Trials by Mr. Willans, before the Institution of Civil Engineers last year, continual reference was made to this diagram, and Mr. Willans has frequently thanked me for making him acquainted with it. With Mr. Willans I devised a method of experimenting on the latent heat of evaporation on a large scale to clear up for me some doubts I had about Regnault's similar experiments. We made accurate experiments very easily with a hundredweight of steam at each trial, and several tons of cooling water in the calorimeter, and with the result that Regnault's experiments were completely confirmed. Out of those experiments came the investigations which gave me the diagram in its present form. There is something very stimulating in the atmosphere of kindred souls, and nothing has helped me more in my thermodynamic researches than the intelligent intercourse which I enjoyed with Mr. Willans while I was witnessing and discussing these economy trials at Thames Ditton in 1887.

I give now only one illustration of the application of the diagram to the graphic solution of problems relating to the duty of steam in the steam-engine. In the paper I propose to read before the Institution of Civil Engineers there will be more illustrations of the same kind. That paper cannot be read this session.

The two curves drawn across the diagram near the top are reference curves, for the pressure of saturated steam at different temperatures.

Problem: Steam at pressure 106 pounds per square inch gross is admitted and expanded until the pressure falls to 10 pounds, and it is then exhausted against a back pressure 3 pounds per square inch. The feed water is supplied at 333° C. absolute. Show upon the diagram what is the theoretical duty of the heat expended under those conditions and in what order that duty is performed.

From temperature 333°, *m*, on the primary curve A draw a vertical line down to the base of the diagram, *m z*. The area to the left of this line represents the energy already possessed by the water at that temperature.

Through 106 on the pressure curve draw a temperature line *a c*, from A to E, that is seen to be at temperature 440° C. absolute. The intersection of this line with the I curve is lettered *b*. The I curve is the graph of the intropy point. Entropy includes the energy of the *p v* of the substance. By intropy I mean the same as entropy, only excluding the *p v* of the substance. The intropy refers to internal energy only. Draw verticals to the base line through *b* and *c*. The *p v* of one pound of steam is represented by the area of the rectangle *b c z z*. Through 10 on the pressure curve draw the temperature line *d h*, that is, at temperature 363° C. All temperatures are given Centigrade absolute. Take *f* in *e h*, so that *f h* is the same part of ·11136, which *d h* is of A H. (This is really not necessary; the curves β and H enable this to be dispensed with, but at present the diagram will be best understood if short cuts are not adopted.) Draw *b f*, and the vertical *f z*. When the steam was admitted to the cylinder, the work done was *b c z z*, or θ . *b c*. During expansion, work equivalent to the area *a b f d* was performed in horizontal bands as the intropy point travelled from *b* to *f*, less the area swept by the intropy vertical as it travelled from *b z* to *f z*. At the end of the expansion, before exhaust, the work done upon the piston is the area *d a c h* + the area *f h z z*. If the back stroke were made against the ten pounds pressure, the work *f h z z* would be cancelled, and the work done would be that represented by the horizontal band *d a c h* only. The back pressure is only three pounds on the square inch. Set off a line *h k*, length = 10 on any scale, and mark off *k l* = 3. Draw the vertical *g z* through *l*. The back pressure work is the area *f g z z*, and the total work done by one pound of steam is *d a c h* + *g h z z*. The total heat expended in performing this work is the area *m a c z z m*. Of that the area *m a z z m* is that which increased the temperature of the water from 333° to 440°. The remainder of the area is the latent heat of evaporation at 440°. It is an easy matter to reduce all this to an arithmetical form. The practical man can here see actually what he is doing, and the effect of hot feed and variations of back pressure and all the questions about higher pressures, superheating, &c., can be readily answered without any of the hazy doubt which in some minds always hangs about ill-understood mathematical expressions.

It was while engaged in writing a series of papers on "Safety Valves and Steam in Motion," in *The Nautical Magazine*, in 1871, that my thoughts became first directed to the ether-pressure theory. I discontinued the papers, as I believed then, only for a month or two until I could work out the problem. It has taken me all my private time from that date until now. My object all along has been the simplification of thermodynamics for engineers. Those who care only for results and have no desire to pry into the occult arrangements in nature whereby these results are produced, may, if

they choose, ignore ether-pressure altogether, and the simplification I have obtained will still hold good for their use. They need only accept that the heat of segregation is, somehow, a constant at all temperatures, and that the 1·4 ratio is merely a deduction from experiments; I am sure *they* will never care to put the question,—Where does the latent heat hide? I have, however, thought it best to write this paper from my own standpoint, and I have therefore not hesitated to place before you, this evening, some very startling statements about the universe we live in—statements which I think are well calculated to provoke profitable thinking, rising far above and extending far beyond the question of the economy of the steam engine in which they have had their origin.

APPENDIX.

The following notes are to some extent a repetition of the substance of the Paper in another form. As the whole subject is not very simple, it is thought that these notes will be useful to anyone desiring to understand the Paper.

The object of the author has been to obtain a graphic simplification of thermodynamics. He has been guided to such a simplification by certain considerations regarding the pressure of the gravitational ether, believed in by Newton, Faraday, and many other eminent physicists. All those who disbelieve in action at a distance must recognise that there is in space contiguous to the earth, a medium pressing upon the earth, with such a resultant as is capable of producing in any mass on the earth's orbit a sunward accelerity equal to that of the earth.

He calculates what that effective force must be on a bar of platinum placed radially on the earth's orbit, its length the equatorial diameter of the earth. That force he takes to be the measure of the slope of the ether-pressure at the earth's orbit. This slope is the gradation of the diminution of ether-pressure, below that of the ether at an infinite distance from any aggregation of matter. This diminution at any place he calls the sub-pressure of the ether at that place. That due to the sun's mass is the solar sub-pressure, and that due to the earth is the terrestrial sub-pressure. He then calculates these sub-pressures at the earth's surface, and the solar sub-pressure at the surface of the sun.

The great magnitude of these forces almost carries the investigation out of the sphere of rational consideration. They are nevertheless what is necessary to bend the course of the earth in its flight, if Newton's view of the nature of gravitation is accepted, and as the calculations are all very simple, the author has thought that, as he has put the facts, many who have never lifted up their thoughts to such a study of nature, may be led to do so, and, attracted by paradox, may develop in themselves new veins of profitable thought.

The author, treating these enormous pressures as realities, shows how, with a molecular ether, they may account for all physical phenomena. In thermodynamics this hypothesis explains where latent heat hides, that the constitutional heat of steam, or any gas, from a state of aggregation at absolute zero consists of two quantities of energy—one the energy of segregation, a constant at all temperatures for the same molecular gas state; and the other, a quantity measured by $3\frac{1}{2}\ p\ v$, and that it requires the γ ratio of specific heat to be 1·4.

Now, laying on one side, out of further consideration, all that has been said about the ether-

pressure, the author submits for your consideration the temperature-entropy diagram or thetaphi diagram for steam—the plate in the paper—as a practical valuable simplification of thermodynamics. The Second Law of Thermodynamics is equivalent to saying that for each point on a thetaphi diagram there is one characteristic state for the substance. That is, proceeding from any state-point by any series of transformations denoted by any graph, when the same point is again arrived at, the initial condition of the substance is also attained.

The author has for many years been striving to accomplish the reconciliation of the gas field and the vapour field on the diagram. Until 1887 he could not do so without violating the Second Law. He has now got over that difficulty, not by any guess or assumption, but by strict mathematical treatment of the problem. In order to explain the steps in that reasoning it is necessary to explain the symbols used :—

p = pressure in any units.
v = volume in such a unit that unit $p\,v$ is the mechanical equivalent of the unit of heat.

The unit of heat and of energy employed in this paper is the specific $p\,v$ of hydrogen gas per degree of temperature. What the specific heat of water is, is not known accurately, and, even if it were known, it would not be commensurable with any thermodynamic quantity. Hydrogen is an element, and it is the standard unit in the arithmetic of chemistry. The specific $p\,v$ of hydrogen is also the natural unit in the arithmetic of thermodynamics. Fortunately its magnitude is almost identical with that of the water unit of heat to which we have been so long accustomed, but which has now to be altered to conform with Rowland's recent very careful experiments.

The proposed new unit of heat and of energy in thermodynamics, the specific $p\,v$ of hydrogen gas, is 1,386 foot pounds for the Centigrade degree, or 770 foot pounds for the Fahrenheit degree.

The specific heat of water is taken to be 1·0106, according to the new unit. This is Rowland's determination for the specific heat of water for the mean temperature of the calorimeter in Regnault's experiments on the latent heat of steam.

The ratio of the two specific heats is taken to be 1·4, as it is, practically for the permanent gases. Szathmari's experiments on the velocity of sound, in 1878, makes $\gamma = 1{\cdot}4027$. The author has shown, in a paper which was read before the Physical Society on February 25, 1885, that, according to Regnault's experiments on the specific heat of steam, the specific heat of steam is about ·38, and not ·48, as deduced by Regnault.

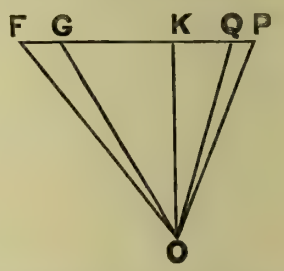
For the thetaphi diagram the heat of segregation is taken to be 501·4, plus the water heat at 273°, and the specific gas heat of steam at 273° is taken to be $\frac{7}{m}$, as in the permanent gases, including the $p\,v$. For steam gas that gives ·38976 for the specific heat at constant pressure, and $\frac{5}{m} = {\cdot}27840$ at constant volume.

What has hindered the completion of this investigation for many years is the wrong view taken of steam in relation to perfect gas. The author, and he thinks everybody else also, has considered that where the $p\,v$ was not that due to the temperature, as in ideal gas,* viz., $\frac{2}{m}\,\theta$, that the gasefication was not completed, and that not only the gas heat, but also the heat of segregation as for complete

* To ideal gas the author gives the name gasene, to distinguish it from actual gas, which is really perfect gas, but for which the $p\,v$ is not proportional to temperature.

gasefication, had not been communicated. The following consideration shows that such an assumption is fallacious :—

If the $p\ v$ of ideal gas for unit weight is $\frac{2}{m}\theta$, remembering what is the unit of v, let $\frac{2}{m}x\ \theta$ be the $p\ v$ for saturated steam at temperature θ. Here x is a variable, some function of the temperature, and always less than unity.



The F, G, and P curves on the thetaphi diagram are explained in the I.N.A. paper.

Let O F, O G, and O P, be now drawn parallel to tangent elements of the curves F, G, and P. Let the vertical O K represent $d\ \theta$ of temperature. At O the temperature is θ, and on F P it is $\theta + d\ \theta$.

Between any pair of temperatures, upon any graph, as O G, the $v\ d\ p$ product for gasene is independent of entropy, and therefore a constant product for the same inclination.

Whether O be regarded as on the F curve or on the G curve of the thetaphi diagram, the $v\ d\ p$ will therefore be the same for gasene, but the v and the $d\ p$ are separately different.

$$\text{Write } -d\,\mathrm{G} = \mathrm{G\,K} = -\frac{d\,\phi}{d\,\theta}\,d\,\theta \text{ on the G curve.}$$

$$\text{Write } -d\,\mathrm{F} = \mathrm{F\,K} = -\frac{d\,\phi}{d\,\theta}\,d\,\theta \text{ on the F curve.}$$

$$\text{The length K P} = \frac{7}{m}\,\frac{d\,\theta}{\theta}$$

A variation of x for $d\ \theta$ does not affect the value of $v\ d\ p$, except by a quantity of the second order, viz., $\frac{d\,\lambda}{d\,x}\cdot\frac{d\,x}{d\,\theta}\cdot\frac{d\,\theta^2}{2\,\theta}$, which therefore vanishes at the limit, and is therefore not written in in what follows. Here λ denotes the latent heat at temperature θ.

On any element parallel to O G, between θ and $\theta + d\ \theta$, we have for gasene—

$$\theta\,\frac{d\,\mathrm{G}}{d\,\theta}\,d\,\theta - \frac{5}{m}\,d\,\theta = p\,\frac{d\,v}{d\,\theta}\,d\,\theta$$

$$\frac{2}{m}\,d\,\theta = p\,\frac{d\,v}{d\,\theta}\,d\,\theta + v\,\frac{d\,p}{d\,\theta}\,d\,\theta = d\,\frac{p\,v}{d\,\theta}\,d\,\theta$$

$$\therefore \quad -\theta\,\frac{d\,\mathrm{G}}{d\,\theta}\,d\,\theta + \frac{7}{m}\,d\,\theta = v\,\frac{d\,p}{d\,\theta}\,d\,\theta$$

$$\text{But} \quad -\theta\,\frac{d\,\mathrm{G}}{d\,\theta} = \mathrm{A\,B} = \frac{\theta}{d\,\theta}\,\mathrm{G\,K}.$$

(Here A B refers to the thetaphi diagram, Plate XXX., and G K to the diagram on this leaf.)

$$\text{Therefore} \quad v\,\frac{d\,p}{d\,\theta} = \frac{\theta}{d\,\theta}\,\mathrm{G\,K} + \frac{7}{m}$$

$$\text{Or} \quad v\,d\,p = \theta\,.\,\mathrm{G\,K} + \frac{7}{m}\,d\,\theta = \theta\,.\,\mathrm{G\,P} = \theta\,(\mathrm{G\,K} + \mathrm{K\,P}).$$

On O F we get, similarly, for gasene—

$$\mathrm{V}\,d\,p = \theta\,.\,\mathrm{F\,P} = \theta\,(\mathrm{F\,K} + \mathrm{K\,P});$$

where $\mathrm{V} = \frac{2}{m}\,\frac{\theta}{p}$ and the p and the $d\ p$ refer to saturated steam between θ and $\theta + d\ \theta$. The actua. v for saturated steam $= x\ \mathrm{V}$, therefore, for saturated steam—

$$x\,\mathrm{V}\,d\,p = v\,d\,p = \theta\,.\,x\,.\,\mathrm{F\,P} = \theta\,(x\,\mathrm{F\,K} + x\,\mathrm{K\,P}).$$

The graph O P is for $p\,v = \frac{2}{m}\,\theta$; for $p\,v = x\,\frac{2}{m}\,\theta$ the graph for the constant pressure would be O Q, making K Q $= x$. K P.

The Second Law requires that for appression *per se* the statepoints for saturated steam shall coincide with the thetaphi curve G and therefore, at the limit, with O G in the straight-line diagram. Consequently—

$$\text{since } x\,.\,\text{F P} = x\,.\,\text{F K} + x\,\text{K P} = \text{G Q}$$
$$\therefore \quad \text{G K} = x\,.\,\text{F K}.$$

Therefore for dry saturated steam—

$$\text{A E} = v\,\frac{d\,p}{d\,\theta} = \frac{\theta}{d\,\theta}\,\text{G K} + \frac{7}{m}\,x = \text{A B} + \frac{7}{m}\,x.$$

That is, the segregation latent heat is the same for dry saturated steam as for gasene $= \theta$.A B.

Now, B is a curve of constant area, viz., the area representing the constant heat of segregation, and $\theta\,\frac{d\,\text{B}}{d\,\theta}$ is therefore the measure of A B at the temperature θ. Therefore, in saturated steam, if S = the heat of segregation, the total energy, including its $p\,v$ is, at any temperature, θ

$$= \text{S} + \frac{7}{m}\,x\,\theta = \text{S} + \frac{7}{2}\,p\,v.$$

Saturated steam is, therefore, matter completely gasefied—it is matter travelling in single molecules. Writing $z = 1 - x$, and now denoting by B the horizontal distance from the curve A to the curve B at the temperature θ, and writing $\epsilon = 2{\cdot}3026$—

$$\text{F G} = \frac{2}{m}\,z$$

$$\therefore\ \theta\,\frac{2}{m}\,d\,z = \text{B}\,\frac{z}{1-z}\,d\,\theta.$$

Writing S = heat of segregation, in addition to the heat of liquid water at 273°, and transposing—

$$\frac{2}{m}\,\frac{d\,z}{z} - \frac{2}{m}\,d\,z = \frac{\text{S}}{\theta^2}\,d\,\theta - \frac{1{\cdot}0106}{\theta}\,d\,\theta.$$

Integrate and change signs, and substitute $\overline{\text{F G}}$.

$$\text{C} + \frac{\overline{\text{F G}}}{\epsilon} - \frac{2}{m}\,\log\left(\frac{m}{2}\,\overline{\text{F G}}\right) = \frac{\text{S}}{\epsilon\,\theta} + 1{\cdot}0106\,\log\theta.$$

Here log is the common logarithm.

From this equation the value of F G has been calculated for steam for every experiment reported by Regnault. The pressure of saturated steam at any temperature is that due to starting from G 273 with gasene, whose $p\,v = \frac{2}{m}\,\theta$, and increasing the temperature at constant pressure. The thetaphi graph for that is the curve P, up to θ, and then compressing at constant temperature, for which the graph is the horizontal line corresponding to θ temperature. Compressing the gasene, then, at temperature θ until the gasene statepoint comes to the curve F, the pressure will then be that for saturated steam at that temperature. The travel for this compression of gasene is $\frac{2}{m}\,\epsilon\,\log\frac{p}{p_0}$, where p_0 is the pressure of steam at 273°, and p is that of saturated steam at temperature θ.

Dividing the emission of heat during the compression of actual gas into that due to reduction of $p\,v$ without change of pressure, called collapsing, and that due to the increase of pressure with $p\,v$ constant, called appression, and reserving the term, compression, for the combined action, it is neces-

sary, in order to fulfil the Second Law, that, when the point for appression-*per-se* comes to the curve G, liquefaction should commence. The statepoint of compression must be always $\frac{7}{m}z$ in advance of the appression-*per-se* point. The $\frac{7}{m}z$ is the entropy shift for collapsing as above defined.

$$\text{E F} + \text{F G} = \frac{5}{m}z + \frac{2}{m}z = \frac{7}{m}z.$$

Completing the thetaphi diagram for steam according to the above deduction, the formula for the pressure of the steam of water comes out to be, for millimètres of mercury,

$$\log p = [0{\cdot}5910552]\,\text{F G} + 25{\cdot}3379 - [0{\cdot}7462505]\log\theta - [3{\cdot}4816439]\frac{1}{\theta}$$

Here, the numbers within brackets are the logarithms of the co-efficients. The value of F G is found from the previous equation, as was explained.

For ice steam the formula does not contain F G, and on account of the heat of liquefaction of ice there are other changes in the formula. It is—

$$\log p = 13{\cdot}35517 - [3{\cdot}4476028 - \log\theta] - \log\theta$$

As before the brackets stand for $\log^{-1}$.

According to these formulæ the pressures for every experiment made by Regnault have been calculated, and a wall diagram showing the results was exhibited at the meeting. The pressures obtained agree throughout more closely with Regnault's experimental results than do the pressures calculated by Regnault's exact formulæ.

The very slight divergence from coincidence at the very highest temperatures would disappear if at that temperature the specific heat of water slightly increased, but the difference is well within the limit of errors of observation, and no variation of specific heat can therefore be with certainty deduced from it.

The latent heat and the "total heat" are also in agreement with Regnault's experiments.

DISCUSSION.

Professor J. H. Cotterill, F.R.S. (Associate Member of Council): Sir John Hay and gentlemen, it is now some years—I think it was in 1880—I had the pleasure of making some remarks on Mr. Macfarlane Gray's former paper, and I said then that I thought the great difficulty in his way was that he could not quite explain how to reconcile his results with the Second Law of Thermodynamics. The Second Law no doubt always gives a good deal of difficulty to thinking students. They at first accept it merely on authority, and it is only afterwards that, by reflection, they feel convinced it is part of the constitution and course of nature. I am very glad that Mr. Macfarlane Gray has been able to get over this difficulty, and to reconcile his results with a fundamental principle which is as much a part of thermodynamics as the equivalence of heat and work. I think his method is a very interesting way of applying the principles of thermodynamics. His theta-phi diagram, in which the vertical ordinates represent absolute temperatures, while the horizontal ordinates represent the "entropy," or what Rankine called "the thermodynamic function," enables him to deal graphically with thermodynamic problems, especially now that he has accepted the Second Law of Thermodynamics in a very convenient and interesting way. Still we must remember it is only another

way of treating thermodynamics. Thermodynamics remain independent of any molecular hypothesis, such as the ether-pressure theory, independent even of the supposition that heat is a mode of motion. As to the ether-pressure theory itself, Mr. Macfarlane Gray, I am sure, does not expect me to establish such a theory. It is necessary to show that it is consistent not merely with thermodynamics, but with the whole of modern science. All branches of modern science are so united together that you cannot consider one without the other. Of course I cannot undertake to discuss this theory from this general point of view, but I will say this, that the number of results which Mr. Macfarlane Gray has shown to be consistent with it, shows that it is quite possible—quite possible, I say ; I do not say it is so, or even that it is probable—that it has elements of truth in it, and therefore I think we are very much indebted to Mr. Macfarlane Gray for the time he has spent, and the ingenuity he has displayed, in this work of attempting to establish thermodynamics to some extent on a new line, and of *perhaps* obtaining a rational theory ; obtaining, for example, thermodynamically a relation between the pressure and the temperature of steam, which shall be not merely the empirical result of experiment, but which represents the true theoretical law. I am far from saying that he has done this, but I do think he is entitled to our thanks for attempting to do it. Now I should like, descending from the region of the ether to the ordinary level, to ask him one question about those important experiments, the total heat of evaporation of water, which were carried out under his joint supervision with Mr. Willans. Evidently such experiments on heat are conducted to a *rough* degree of accuracy much more easily when they are conducted on a large scale. Let us say, for the sake of argument, that to half per cent. it is best to operate on a large scale. I have a doubt, and I should like to ask Mr. Macfarlane Gray this question, how far it is possible in large scale experiments to be sure that the temperature of the water tank is uniform throughout, and to measure the average temperature with that accuracy which is required in order to get your results with extreme accuracy, such accuracy, for example, as Regnault obtained by experimenting on a small scale.

Mr. P. Willans (Visitor) : I will only say a word or two, Sir John, if I may be allowed. Mr. Macfarlane Gray has mentioned my name in connection with some experiments at Thames-Ditton, or I should not have spoken at all, because, as Professor Cotterill has shown us, it is a large subject to go into, and one which very many others who are here are better able to deal with than I am. Mr. Macfarlane Gray mentioned those experiments, and thanked me for some help which he was pleased to say I gave him ; but it seems to me the help was all the other way. Mr. Macfarlane Gray gave me a great deal of help in a matter which I knew very little about when I began. I think, as to the larger question, it would be impertinence for me to say anything, especially after such an authority as Professor Cotterill has hesitated to do so ; but about the beauty of the theory, as far as I have been able to follow it, it seems to me impossible to speak too highly. It leads us, as Professor Cotterill said, far beyond the question of thermodynamics as applied to steam, and I think having explained this by his theory so far, we shall look to Mr. Macfarlane Gray to explain also by it all chemical and electrical phenomena, when he has time to do it, as I hope he may have. We must remember that he has spent eighteen years on this matter, and, as I have said already, it would be impertinence in anyone who has not devoted a large portion of his time to similar investigations to express an opinion offhand on the general question of the truth of the theory. Now, with regard to the thetaphi diagram itself, and especially with regard to its use in the plotting down of investigations connected with steam, it is possible for me to speak from experience, because I have used it for some time ; and, as a practical matter, it seems to me to be by far the best thing that was ever brought before practical engineers. It is the easiest possible method to work with, when you once get it into your head, because it does not necessarily require any mathematics, and still tells you everything you

want to know. I say this from experience, and I can speak with certainty. I should strongly advise all practical engineers, even if they do not wish to follow Mr. Gray in his physical investigations, to make themselves acquainted, as soon as they can, with this clear and most instructive diagram. Professor Cotterill asked one or two questions which Mr. Gray no doubt will answer; but I may, perhaps, be allowed to say one word also. Professor Cotterill asked whether he thought that the investigations at Thames-Ditton, as to the latent heat of steam, were very accurate. I should say that all those experiments, and we only made one of each kind, practically were identical with those of Regnault, except in those cases where there were differences which we could quite well understand. If we had desired to get very minute accuracy, we should have tried ten or a dozen experiments, or perhaps more, at each temperature, as Regnault himself did; but when we found that at any temperature the results of our single experiments with active boiler steam, made on a large scale, agreed almost exactly with the mean results of the many careful laboratory experiments of Regnault, it appeared to be unnecessary to proceed further with them.

Mr. J. Macfarlane Gray (Member of Council): Mr. Willans having replied to the question of Professor Cotterill, instead of adding any remaks of my own, I will refer to what Newton has written about ether-pressure. I had not read his final observations on this subject until after my paper was printed. Newton, in a conversation with the Hon. Robert Boyle, had mentioned this subject, and on February 28, 1678, in a letter to Boyle, he says: "For my own part I have so little fancy to things of this nature, that, had not your encouragement moved me to it, I should never, I think, have thus far set pen to paper about them." On February 25, 1692, he attacks Bentley for having misrepresented his views, and he says: "That gravity should be innate, inherent, and essential to matter, so that one body can act upon another at a distance, through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it." And finally, July 16, 1717, he prefaces his treatise on optics with this advertisement: "To show that I do not take gravity for an essential property of bodies, I have added one question concerning its cause, choosing to propose it by way of a question, because I am not yet satisfied about it for want of experiments." From that question I make the following quotation: "Is not this medium within the dense bodies of the sun, stars, planets, and comets, rarer than in the celestial spaces between them? And, in passing from them to great distance, does it not grow denser and denser perpetually; and thereby cause the gravity of those bodies towards one another, and of their parts towards the bodies; every body endeavouring to go from the denser parts of the medium towards the rarer? For, if this medium be rarer within the sun's body than at its surface, and rarer there than at the hundredth part of an inch from its body, and rarer there than at the fiftieth part of an inch from its body, and rarer there than at the orb of Saturn, I see no reason why the increase of density should stop anywhere, and not rather be continued through all the distance from the sun to Saturn, and beyond. And though this increase of density may at great distance be exceeding slow, yet if the elastic force of this medium be exceeding great, it may suffice to impel bodies from the denser parts of the medium towards the rarer, with all that power which we call gravity." He then shows, by comparing the velocity of light with the velocity of sound, "that the elastic force of this medium, in proportion to its density, must be above 700,000 × 700,000 (that is 490,000,000,000) times greater than the elastic force of the air is in proportion to its density." As the velocity of light is much greater, and the velocity of sound less than Newton took them to be, the number given has to be nearly doubled. I have given these quotations because they seem to have been quite lost sight of in modern books, and to show that the enormous pressures introduced in my paper are only the numerical statement of Newton's views. I draw attention to the

dates of the three statements, 1678, 1692, 1717--there is an interval of fourteen years, and then an interval of twenty-five years. Newton worked at this idea for thirty-nine years, and leaves his work summed up in a question, and it is in the same position yet. I have been only eighteen years at it. If anyone is inclined to discourage such studies, let him read the following justification, given at the same time by Newton—"The main business of natural philosophy is to argue from phenomena without figuring hypotheses, and to deduce causes from effect, till we come to the very first cause, which certainly is not mechanical; and not only to unfold the mechanism of the world, but chiefly to resolve these and such like questions. What is there in places almost empty of matter, and whence is it that the sun and planets gravitate towards one another, without dense matter between them? Whence is it that Nature does nothing in vain, and whence arises all that order and beauty which we see in the world? . . . And though every true step made in this philosophy brings us not immediately to the knowledge of the first cause, yet it brings us nearer to it, and on that account it is to be highly valued."

The Chairman (Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S.): Gentlemen, I am sure you will wish me to convey your thanks to Mr. Macfarlane Gray for his very interesting paper.

ON THE FORMATION OF MARINE BOILER INCRUSTATIONS.

By Professor V. B. Lewes, F.C.S., F.I.C., Royal Naval College; Associate.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 11th, 1889; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

In the older forms of marine boilers, working at comparatively low pressures, sea water was almost universally employed; but with the introduction of high-pressure tubular boilers the amount of deposit formed was so serious, and the difficulty of cleaning out the incrustation from between the tubes so great, that it became almost imperative to discontinue the use of the sea water, and to rather accept the expense of supplying the boilers with distilled water, than risk the burning and destruction of the tubes and plates in inaccessible portions, where the deposit had to be allowed to collect until the time could be spared for a complete clean out and refit. But, after several years' experience of this system, it is found that the trouble has only been transferred from the steam boilers to the distilling apparatus, and that the enormous deposits formed in the latter cause them frequently to break down or become in some way or another unfit for use, so necessitating the introduction of sea water into the boiler to eke out the supply of distilled water from the condensers.

Under these circumstances, I have thought that it might be acceptable to bring before the members of this Institution the results of a series of experiments recently made in the laboratories at Greenwich, together with some suggestions founded upon them, which might be of value in attempting a solution of this very serious evil.

I propose in this paper to show the nature and cause of the deposits formed from each class of water used in marine boilers, and then, by a study of the characteristic properties of each constituent of the incrustation, to arrive, if possible, at a method for its prevention.

The waters at present in use in marine boilers may be classified as—

(1) Sea water.

(2) Distilled water.

(3) Mixtures of (*a*) sea water and distilled water; (*b*) sea water and fresh water.

By fresh water is here meant the water, either from spring, well, or river, which is taken on board when in port, and which, under certain circumstances, is used mixed with condensed water, or sea water in the boiler.

Such water is very variable in composition, but, as a rule, contains as its chief saline constituents the carbonates of lime and magnesia, held in solution by carbonic acid present in the water, and also small quantities of the sulphates of these metals, and traces of common salt.

Sea water contains a far higher proportion of saline matters in solution than fresh water, and also in totally different proportions, as although sea water is only river water concentrated by the evaporative power of the sun's rays during long ages, yet, owing to deposition during the flow of the water down rivers, and also to its being used by certain forms of marine life, calcic carbonate (carbonate of lime), which is the chief saline constituent of fresh water, is reduced to a mere trace in salt water, whilst the salt has become the all-important constituent, and the sulphates of lime and magnesia, together with chloride of magnesium, are also present.

The wide difference in composition of fresh and salt water may be seen from the following analyses :—

SALTS IN SOLUTION IN RIVER AND SEA WATER.

GRAINS PER GALLON.

	River Water. THAMES.	Sea Water. LOWESTOFT.
Calcic Carbonate (chalk)	10·80	3·9
Calcic Sulphate (gypsum)	3·00	93·1
Magnesic Sulphate	0·25	124·8
Magnesic Chloride		220·5
Magnesic Carbonate	1·25	Trace
Sodic Chloride (salt)	1·80	1850·1
Silica (sandy matter)	0·56	8·4
Oxides of Iron and Alumina	0·27	Trace
Organic Matter	2·36	Trace

Distilled water is presumably free from all dissolved solids, but the condenser water always contains some of the lubricants from the cylinder; and in the days of animal and vegetable lubricators, like fat and oils other than mineral, this water, on account of the superheated steam breaking the oils up and liberating fatty acids, caused a large amount of damage to the plates of the boiler; but with the use of mineral oil lubricators of the right kind this trouble is done away with, and a slight coating of organic matter is, as a rule, the only incrustation found in a boiler using distilled and condenser water only.

The great difference existing between sea and fresh water would lead one to expect a wide difference also in the kind of deposit formed from them, and this is found to be the case, as the following analyses of incrustations formed in the boilers of steamers using fresh river water, the brackish water at the mouth of a river, and sea water respectively, show:—

	River.	Brackish.	Sea.
Calcic Carbonate	75·85	43·65	0·97
Calcic Sulphate	3·68	34·78	85·53
Magnesic Hydrate	2·56	4·34	3·39
Sodic Chloride	0·45	0·56	2·79
Silica	7·66	7·52	1·10
Oxides of Iron and Alumina	2·96	3·44	0·32
Organic Matter	3·64	1·55	Trace
Moisture	3·20	4·16	5·90
	100·00	100·00	100·00

These may be taken as typical deposits, and show that with fresh water the incrustation may be looked upon as consisting of calcic carbonate, with small quantities of other compounds; that with a mixture of fresh and salt water the deposit consists of nearly equal parts of the calcic carbonate and sulphate; whilst the sea water gives practically calcic sulphate.

The presence of calcic sulphate exercises a very marked influence upon the condition and physical properties of the incrustation, as, under the conditions in which

it is formed in a boiler, it separates in a crystalline form, and binds the deposit into a hard mass, an action which is also aided by the presence of magnesic hydrate.

A deposit consisting of calcic carbonate only, or of calcic carbonate and traces of the oxides of iron and alumina, sodic chloride, &c., is separated as a soft powder, which remains suspended in the water for some time, and which can fairly easily be removed from the boiler on cleaning; whilst, if calcic sulphate is present, the scale is extremely hard, and generally requires the use of hammer and chisel to detach it from the plates and tubes, an operation which is extremely injurious, and tends to shorten the life of the boiler.

The three principal constituents of boiler incrustations may therefore be looked upon as calcic carbonate, calcic sulphate, and magnesic hydrate, and the causes which lead to their deposition must now be considered.

Calcic carbonate is practically insoluble in pure water, that is to say, it requires more than 10,000 parts of pure water to dissolve one part of the carbonate;* but carbonic acid, which is present in all natural waters, when in contact with calcic carbonate converts it into bi-carbonate, which is soluble, and this forms the so-called "temporary hardness" in fresh waters. On heating such a water the bi-carbonate is decomposed, carbonic acid gas escapes, and the calcic carbonate being insoluble, is deposited. Calcic carbonate is slightly more soluble in saline solutions, such as sea water, than in pure water, but the difference is so small that the above may be looked upon as applying equally to fresh and salt water.

Calcic sulphate is to the marine engineer the most important constituent of boiler incrustation, and its separation as a deposit from water is dependent upon a totally different class of phenomena to those which bring about the precipitation of the calcic carbonate. Calcic sulphate is dissolved in water by the solvent power of the water itself, and not through the agency of carbon dioxide, and therefore merely boiling water at ordinary pressures does not suffice to cause its deposition, and for this reason, it forms, together with soluble magnesium salts, the "permanent hardness" of fresh water.

The solubility of calcic sulphate in pure water varies very considerably with the temperature.

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* Soluble in 16,000 parts pure water according to Brande; 12,858 according to Kremers; 16,000 to 24,000 according to Buchholz.

100 Parts of Water, At a temperature of	Dissolve Calcic Sulphate.
32° F. or 0° C.	0·205
41° ,, 5°	0·219
53·6° ,, 12°	0·233
68° ,, 20°	0·241
86° ,, 30°	0·249
95° ,, 35°	0·254
104° ,, 40°	0·252
122° ,, 50°	0·251
140° ,, 60°	0·248
158° ,, 70°	0·244
176° ,, 80°	0·239
194° ,, 90°	0·231
212° ,, 100°	0·217

So that calcic sulphate is most soluble in water at 95° F. or 35° C.* roughly, one part of calcic sulphate being dissolved in 400 parts of water; and, inasmuch as the solubility of the salt is considerably decreased at 212° F. or 100° C., if a saturated solution be taken at 95° F. or 35° C., and is then heated to 212° F. or 100° C., a precipitation of a portion of the calcic sulphate will take place.

Calcic sulphate is much more soluble in a saline solution, such as sea water, than it is in fresh water, but its solubility rapidly decreases, (1) on concentration of the saline solution, and (2) on increase of temperature and pressure.

To trace the effect of concentration on the calcic sulphate a considerable volume of sea water was taken and slowly evaporated at ordinary atmospheric pressure, the composition of the water being ascertained by analysis, and the density of the water being taken at successive stages of the concentration.

Sea water having a density of 1·027 ($\frac{1}{32}$ salinometer) was allowed to concentrate

* Poggiale, Ann. Ch. et Phys.

by exposure to air until it had a density of 1·029, and it was then evaporated, and analyses made at the following densities :—

Saline Constituents per Cent.*

Density	1·029	1·05	1·09	1·225
Sodic Chloride	2·6521	4·4201	7·9563	23·8689
Calcic Sulphate	0·1305	0·2175	0·3915	None
Calcic Carbonate	0·0103	0·0171	None	None
Magnesic Carbonate	0·0065	0·0032	None	None
Magnesic Chloride	0·2320	0·3865	0·6960	2·0880
Magnesic Sulphate	0·1890	0·3150	0·5670	1·7010

The deposits formed during concentration were carefully collected and analysed, and it was found that the deposit formed up to the density 1·05 consisted of basic magnesic carbonate only. The deposit taking place between densities 1·05 and 1·09 consisted of

Basic Magnesic Carbonate and Hydrate	17·6
Calcic Carbonate	82·4
	100·0

no trace of calcic sulphate having yet come down, whilst between the densities 1·09 and 1·225 the deposit consisted of pure calcic sulphate only, so that on the concentration of the sea water three distinct stages of deposition may be traced :—

(1) Deposition of basic magnesic carbonate.

(2) Deposition of calcic carbonate with remaining traces of the basic magnesic carbonate and hydrate, and, finally,

(3) Deposition of the calcic sulphate.

If the sea water be heated and concentrated above a density of 1·225, the salt commences to crystallise out.

The deposition of the calcic sulphate during the concentration of the sea water is

* Density or sp. gravity 1·025 at 0° C. = $\frac{1}{3}\frac{1}{2}$ Salinometer = 10° Densimeter.
,, ,, 1·05 ,, = $\frac{2}{3}\frac{2}{2}$,, = 20° ,,
,, ,, 1·09 ,, = $\frac{3}{3}\frac{3}{2}$ (roughly) ,, = 30° ,,
,, ,, 1·2 ,, = $\frac{7}{3}\frac{7}{2}$,, = 70° ,,

due to two causes, in the first place, although it is more soluble in a dilute solution of salt than in fresh water, yet it reaches its maximum solubility at a density of 1·033, and after this point concentration of the saline solution diminishes the amount which can be held in solution, and the calcic sulphate is perfectly insoluble in a saturated brine. The second cause for its deposition is the rise in boiling point which accompanies the increase in density; the higher the temperature the less the solubility of the calcic sulphate, so that when a temperature of 284° to 302° F., or 140° to 150° C. is reached it becomes perfectly insoluble, both in sea and fresh water.

These experiments show that, if sea water be boiled merely under atmospheric conditions, it would be quite possible, by taking care that its density does not rise above a certain point (1·09), to prevent the deposition of the calcic sulphate; but any such regulation of the density is rendered abortive by the fact that pressure and consequent raising of the boiling point acts upon the calcic sulphate in solution in exactly the same way as concentration and increased temperature, so that in the older forms of boiler, working even at a comparatively low pressure, most of the sulphate was deposited, whilst in the high-pressure boilers now in use, if the water contains the smallest trace of calcic sulphate, it will be deposited; and, as any deposit formed amongst the tubes in such a boiler would be almost impossible to get at to clean away, it is practically impossible to use sea water in them, and they are supplied with the water from the condenser augmented by distilled water made in special distilling plant. The question has been raised as to whether, if sea water were mixed with distilled water so as to reduce its density very low, it would deposit the calcic sulphate; but experiment shows that, even if sea water is mixed with many hundred times its bulk of distilled water, the minute trace present is deposited under pressure when the temperature approaches 284° F. or 140° C. So that when, through a breakdown in the distilling apparatus, sea water has to be used with the condenser water in even very small quantities, slight scale is sure to be formed. When a saline solution containing calcic sulphate is heated under pressure or concentrated until calcic sulphate begins to separate, the sulphate will continue to precipitate even after the liquid has cooled down or the pressure has been removed; and, finally, when calcic sulphate has separated at a high temperature or pressure from sea water, even though the water has only the ordinary density (1·027), the rate at which the sulphate will re-dissolve is so extremely slow that the re-solution is practically nil.

These two last properties are due to the form in which the calcic sulphate separates from sea water under pressure. Calcic sulphate occurs in nature as gypsum, in which each molecule of calcic sulphate is combined with two molecules of water of crystallisation: when calcic sulphate is deposited from sea water in a boiler it comes down in small crystals containing two molecules of calcic sulphate to one of water; whilst, after deposition in the boiler and in contact with the heated plates and tubes, it undergoes a further change of crystalline form, loses all water, and becomes "anhydrite," which is

pure calcic sulphate free from water of crystallisation, and it is this change in crystalline form which binds deposits containing it into such a hard mass.

The presence of magnesic hydrate in boiler deposits has given rise to many theories to account for its formation, the most generally accepted one being that it is due to the mutual decomposition of water and magnesic chloride, which give rise to magnesic hydrate and hydrochloric acid, the action being accelerated by the presence of metallic iron.

When sea water is evaporated with a large surface of metallic iron present in it, no free chloride can be detected in the distillate until four-fifths of the solution has been distilled over, whilst if the sea water be evaporated alone, it can be taken nearly to dryness without any decomposition. There is no doubt, however, that at a high temperature under pressure in marine boilers this decomposition takes place, but only to a very small extent, some of the deposit of the magnesic hydrate formed being due to the decomposition of the trace of magnesic carbonate first deposited from the water, in contact with the heated tubes, whilst the formation of the bulk of the magnesic hydrate present is explained by the following experiments. A sample of freshly precipitated and carefully washed calcic carbonate was boiled for some hours with a dilute solution of magnesic chloride and the steam led through baryta water. After a quarter of an hour carbon dioxide (carbonic acid gas) was freely evolved and gave a dense precipitate, whilst at the end of the operation the solution in the flask contained a large proportion of the calcium as calcic chloride, and the precipitate remaining was mostly magnesic hydrate. The same experiment was repeated, using sea water instead of the made up magnesic chloride solution, with exactly the same result.

In this reaction, taking place in a boiler, the magnesic chloride and calcic carbonate mutually react upon each other, soluble calcic chloride and magnesic oxide are formed, and the magnesic oxide uniting with water forms magnesic hydrate, which is precipitated, carbon dioxide escaping.

This explains many points which the former theory leaves untouched—for instance, the fact of calcic carbonate being absent from marine boiler deposit, or, if present, in only very small quantities; and also that chloride of iron is not found in the water of the boiler, which would be the case if any corrosion or pitting was due to the action of free hydrochloric acid.

In many analyses of boiler deposits no magnesic hydrate is returned, but considerable proportions of magnesic carbonate, which naturally would be formed by the

magnesic hydrate absorbing carbon dioxide on exposure for any length of time to the air.

Sodic chloride, magnesic chloride, and sulphate are not found as usual constituents of boiler scale; but in cases of heavy incrustation, pockets are found in the deposit filled with microscopic crystals of these salts which have slowly filtered in solution into cavities in the incrustation, and have been deposited there on evaporation of the liquid.

In some heavy deposits the method of formation of the incrustation can be clearly traced, and affords an insight into the changes which must take place in it after deposition.

A sample of incrustation attached to a tube cut from the boilers of H.M.S. *White Swan*, and which had, during three years' service on the East Indian station, completely filled up the spaces between the tubes in an inaccessible portion of the boiler, showed, on cutting a section, that two distinct forms of deposit could be traced; on the sides of the tubes a hard crystalline deposit of a fibrous structure had formed, whilst filling in the spaces between these highly crystalline layers was a softer kind of deposit, soft and loose on the exterior, but resembling alabaster in the interior, where not in contact with air.

A portion of the crystalline deposit from the upper surface of the tube was taken, carefully freed from any of the less crystalline part, and was analysed, giving—

Calcic Sulphate	93·90
Silica	5·16
Sodic Chloride	·27
Moisture	·67
	100·00

The silica was evidently fine sand which had settled out from shore water, and the moisture had most probably been absorbed from the air, so that this crystalline layer was practically pure calcic sulphate. The soft, outer portion of the second deposit which had evidently been formed by the action of air, on analysis, gave—

Calcic Sulphate	89·33
Silica	·52
Magnesic Carbonate	6·49
Water	3·66
	100·00

and the inner portion on the surface of which the above had formed, selecting a portion free from pockets or cavities, gave—

Calcic Sulphate...	84·27
Magnesic Hydrate	7·04
Silica	1·94
Oxides of Iron and Alumina	1·10
Water	5·65
	100·00

Whilst a portion containing a cavity in which were microscopic crystals gave—

Calcic Sulphate...	46·06
Sodic Chloride	38·66
Magnesic Hydrate	4·16
Silica	1·09
Oxides of Iron and Alumina	·65
Water	9·38
	100·00

The dual nature of the incrustation was even more marked in a specimen of heavy deposit got from the back of the boilers of H.M.S. *Northumberland*, and which could only be got out whilst she was undergoing a thorough refit, and had been probably forming from three to six years, during which period she had been mostly in the Channel. The boilers had been worked at a pressure of about 25 lbs., and jet condensers used. The hard crystalline portion gave—

Calcic Sulphate...	91·31
Magnesic Hydrate	1·77
Sodic Chloride	1·39
Oxides of Iron and Alumina	0·12
Moisture	5·41
	100·00

Whilst the increase of magnesic hydrate was very marked in the non-crystalline portion—

Calcic Sulphate...	79·76
Magnesic Hydrate	5·02
Sodic Chloride	4·29
Calcic Carbonate	0·97
Oxides of Iron and Alumina	0·52
Silica	1·10
Moisture	8·34
	100·00

The crystalline crusts of calcic sulphate are always thickest and purest, and, for this reason, hardest in contact with the tubes or plates of the boilers where they

have been most heated, but one also finds these layers throughout the deposit, in many cases having a nodular form; and I think this goes to prove that after the deposit has come down as a mud, the calcic sulphate being as deposited already in small dense crystals, sinks through the lighter portions, and forms first a thin, and eventually a thick coating, which, by continuous heating under pressure, changes its crystalline form, giving up moisture, and becomes "anhydrite," whilst the deposit above it gradually becomes thicker and thicker, and more crystallisation of the calcic sulphate takes place, pieces of mill scale and other foreign substances present in the mud forming nuclei round which the "anhydrite" crystallises; the lighter portions, consisting of magnesic hydrate and traces of calcic carbonate, settling into any spaces that remain, and completing the deposit.

These deposits may be taken as a fair example of the incrustations formed by sea water in marine boilers, and, as before pointed out, the admixture of fresh river water would only alter its characteristics by increasing the proportion of calcic carbonate and magnesic hydrate present.

When distilled water only is used, a slight coating is formed, practically consisting only of organic matter, whilst if at any time through a break-down in the distilling apparatus sea water is mixed with the distilled water, a thin and very hard scale of calcic sulphate is formed. An incrustation of this character gave on analysis :—

Calcic Sulphate	90·84
Magnesic Hydrate	·75
Sodic Chloride	1·41
Silica	·85
Copper Carbonate	1·11
Oxides of Iron and Alumina	·24
Organic matter	2·96
Moisture	1·84
	100·00

This scale is of great interest from the presence in it of the carbonate of copper. It is well known that distilled water has a far greater solvent effect upon metals than a water containing salts in solution, and it is quite conceivable that the distilled water from the surface condensers attacks the brass and copper tubes and fittings, and deposits the copper on the tubes of the boiler, although in only small quantities; and it is interesting to note that the green spots due to the presence of the copper are all on the under side of the scale, that is, in contact with the metal of the boiler tubes, showing that in all probability it had been deposited, as suggested, from the water in the boiler, and in contact with the iron would set up local galvanic action and tend to produce pitting.

A scale of this character is not as a rule very thick, in the case quoted being only one-sixteenth of an inch in thickness in the tubes, and three-sixteenths of an inch on the crown of the furnace.

The importance of preventing boiler incrustation, and thereby saving the enormous waste of fuel and injury which it entails, has not been without its effect upon the minds of inventors, and almost every conceivable substance, from potato parings to complex chemical reagents, have from time to time been patented for this purpose, but they have all more or less failed for marine boilers, because either they have had an injurious effect upon the metal of the plates, or else have produced an enormous bulk of loose deposit which although easily cleaned out, if the various parts of the boiler were accessible, and if it were only being used intermittently, yet in a marine boiler continuously working, rapidly chokes the portions between the tubes, and brings about an even worse state of affairs than that originally existing.

For these reasons, no treatment of sea water in the boilers themselves is practically possible, and with high pressure tubular marine boilers the water used must either be condenser water made up to the required bulk with distilled water, as is at present done, or else the condenser water must be augmented by sea water especially prepared for the purpose in a separate apparatus before being supplied to the boilers; and it is to this latter method that I wish now to specially call your attention, as the high solvent action of distilled water upon metals and the cost of its production are primary objections to its use, whilst the constant breaking down from choking of the distilled water apparatus generally ends in the admixture of sea water with the condenser water and the formation of scale in the boilers.

From the data I have brought before you, and from the conditions under which the incrustations are formed, it is evident that if water is boiled under a pressure of 70 lbs., all the calcic sulphate and the carbonates of lime and magnesia will separate out, and by heating water to such a pressure for an hour in an auxiliary vessel, I have experimentally proved that water is obtained which will yield no further deposit when used in the marine boiler. The drawbacks to this process, however, would be that a strong boiler would be required to stand the necessary pressure, and that inasmuch as the deposits formed in this auxiliary boiler would be of the same kind as in the old marine boilers, it would necessitate constant stoppages for cleaning out, as from the binding and hardening effect of the calcium sulphate no mere blowing off would get rid of it, and in the method for treatment of sea water which I should suggest to you, we can take advantage of chemical as well as mechanical means for the separation of all salts in solution which are liable to produce deposits.

In all the more successful of the anti-incrustators sodic carbonate plays the most important part; indeed, several well-known and much-used articles of this class for

fresh water boilers are only soda disguised by some cheap colouring matter and sold at a high price, and they act by converting calcic sulphate into calcic carbonate; sodic sulphate, a salt nearly as soluble as the sodic chloride itself, being at the same time formed, and the calcic carbonate precipitates as a soft powder, and there being no calcic sulphate to harden it, it can readily be got rid of.

From time to time the use of sodic carbonate in marine boilers has been advocated, but the serious drawback to its use is that it throws down the magnesium salts as carbonates, and so forms a bulky precipitate which, unless got rid of within a few weeks of its deposition, bakes to a hard mass and forms a bad form of deposit.

In order to separate the whole of the calcium and magnesium salts present, it is only necessary to raise the sea water to the boiling point with the right quantity of soda solution, and after separation of the precipitate formed the sea water will contain nothing but sodic chloride and sodic sulphate, both of which are so soluble that there is no fear of anything depositing, unless the solution were evaporated to a density of 1·2, a degree of concentration never approached in a marine boiler even when sea water was used without admixture of condenser water, except on the rarest possible occasions.

The sea water treated as proposed would have a density of 1·026, about $\frac{1}{32}$ on the salinometer, and would be mixed with the condenser water, which would in the proportions usually taken further reduce this to 1·002, and inasmuch as several tons of freshly prepared water would be daily inserted into the boiler, it would take very many months before an objectionable degree of concentration was reached, so that an occasional blowing off of the boiler when in port is all that would be necessary to entirely eliminate the question of density.

The mixture of condenser water and treated sea water would be far preferable for use in marine boilers to the mixture of condenser water and distilled water, as the action of the distilled water on the plates is done away with by the presence of the saline matter in solution, whilst the cost would be a quarter of that at present incurred for distilled water.

If the engines of a vessel are in good condition, she will approximately require 1 ton of water per 1,000-horse power per 24 hours, to make up the volume of the condenser water to the amount required for the boilers, so that even supposing the engines not to be in good order, and considerable waste to take place, 10 tons per diem would be an outside allowance for even very large vessels. To obtain this amount of treated sea water I should propose the following arrangement.

A cylindrical vessel of 4 tons capacity has sea water run into it from the pipe D (Plate XXXI.) until a mark on the gauge glass E shows that 3 tons have been admitted; the hinged steam-tight door F is now opened, and 40 lbs. of soda crystals are added for each ton of sea water. This amount is sufficient to convert all the calcic sulphate into calcic carbonate, and all the magnesic sulphate and chloride into magnesic carbonate; and this latter being thrown down in the hydrated form, is very bulky; all the taps being closed, steam from the boiler, probably under a pressure of from 100 lbs. to 150 lbs., is blown in until the pressure gauge registers 5 lbs. to 6 lbs., that is, until the temperature becomes about 230° F. or 110° C. Under these conditions the precipitate becomes very dense, and rapidly settles in a small bulk to the lowest part of the boiler as a loose powdery precipitate, which, if the vessel once a week has half a pint of paraffine oil, free from paraffine scale, put into it while it is empty, will show no tendency to cling to the sides. Having reached this temperature, the steam is cut off, and the vessel and contents are allowed to stand for half an hour to allow the precipitate to settle.

This vessel having to withstand so slight a pressure, can be made with every part easily "get-at-able," and would have the tube from which the water was to be blown out at such a depth from the bottom that $2\frac{1}{2}$ tons of the contained water could be blown or drawn off from it, whilst a blow-off cock at the lowest point of the bottom would allow the remainder to be blown or drawn off, and with it most of the deposited matter.

The $2\frac{1}{2}$ tons of water for the steam boilers would on leaving the depositor vessel pass through a chamber fitted with six filter frames made of perforated iron, covered with asbestos cloth, which would entirely free the water from the last traces of suspended matter, and it would now be run straight into the hot-water well or feed-water tank, and being almost at the boiling temperature, could be pumped straight into the steam boiler.

The filter frames, in order to avoid all risk of choking, would be so arranged that they could be readily flushed after each filtration, by such a contrivance as shown in the drawing.

1, 2, 3, 4, 5, 6 are the filtering frames, having each a superficial area of about one square foot. During filtration the cock A is opened and also B, all the others being closed, the water filters through the canvas of the filtering frames, and passes out at B perfectly clear and bright, having deposited most of the precipitate still in suspension on the surface of frame 1, the deposit gradually silting down into the settling recess above cock *f*—the remainder of the deposit being retained in rapidly diminishing quantities by the frames 5, 4, and 3; 2 and 1 having probably little or nothing to do. This filtration may be conducted rapidly if the feed-water tank is large enough to hold the whole charge of treated water, by turning on the steam once more, and forcing the water through the filtering chamber, but if the tank be small the prepared water can

be allowed to filter slowly by its own weight. When this batch of water has filtered through the frames the cock C is opened, and the bottom $\frac{1}{2}$ ton of water is blown out by turning on the steam, and carries with it the deposit from the vessel. C and A are then closed, the vessel refilled, the sodic carbonate added, and the steam once more passed in, and while this batch of water is heating, the cock B is closed, and D and *f* opened, a flush of sea water is allowed to flow in through D, and passes through the filter frames in the opposite direction to which the filtration took place. This washes all deposited matter out of the pores of the asbestos cloth, and the deposit on and at the foot of frame 6 is washed down through *f*. The cocks *e*, *d*, *c*, *b*, *a*, are now opened in order, and in this way all deposit is got rid of down the waste pipe. The flush cock D is now closed, and when all the water has drained out from the filter chamber, the small cocks are closed, and the filters are ready for the next batch of water. Properly conducted, the whole operation would take less than three hours, and as the yield of prepared water is $2\frac{1}{2}$ tons, the 10 tons required would easily be obtained by means of the small apparatus described in twelve hours. Should the supply be required for higher powers, water enough for 25,000-horse power could be obtained from two apparatus of the kind described, which from their small size could be easily fitted without any inconvenience, and as they would be several feet below the water line, the sea water for the boiler and for flushing the filter frames could be directly fed to them without any pumping gear.

In conclusion, I can only hope that the suggestions I have thrown out may help to solve a question which is of the greatest importance to the marine engineer, and that if the form of apparatus I have devised does not meet with general favour, yet that the chemical facts and researches I have embodied in this paper may, in more practical hands than mine, tend to this much to be desired result.

DISCUSSION.

Mr. Thomas (Visitor): I simply want to ask Professor Lewes the question, what distinction he draws between condenser water and distilled water?

Professor V. B. Lewes (Associate): It is that distilled water is water specially distilled, and put into the boiler without having been in contact with the fittings of the condenser. In the condenser water you have distilled water which, in the form of steam, has been passed through the cylinders and been condensed, and which therefore contains some of the lubricators from the cylinders, and also any other matters which it may have picked up.

Mr. Thomas: At the same time it is contaminated distilled water?

Professor V. B. Lewes: Yes.

Mr. Thomas: But it does not contain any of these salts?

Professor V. B. Lewes: No, it does not contain any salts which can be deposited.

Mr. Thomas : Does not plain condenser water, where there is a small proportion of sea water, act perfectly well in the boilers, provided it is not taken up to a density beyond 1 ?

Mr. W. H. White, F.R.S. (Vice-President) : I would suggest that it would be better if Professor Lewes were not catechised, but were allowed to reply at the end of the discussion. Of course, we do not object to questions being put, but I would suggest that they should be put and answered only at the termination of the discussion.

Mr. Thomas : I simply wanted to know whether a small proportion of sea water, fed in with the distilled water, would not answer the purpose perfectly well. The boilers would work without incrustation, because condensed water, I take it, is distilled water contaminated with the oil, and, of course, the effect on the boiler plates, and tubes, and fittings, may be due in a great measure to the contamination of the oils, and not to other matters which are deposited.

Mr. A. L. Jones (Visitor): I am not going to offer any general remarks upon this paper, but merely wish to state a point of difficulty which Professor Lewes has not explained. On p. 336 it is stated that "the second cause of the deposition of the calcic sulphate is the rise in boiling point which accompanies the increase in density, the higher the temperature the less the solubility of the calcic sulphate, so that when a temperature of 284° F. to 302° F. is reached, it becomes perfectly insoluble, both in sea and fresh water." Now these temperatures at which the calcic sulphate is stated to become quite insoluble, and therefore completely deposited, correspond to steam pressures of 35 pounds to 55 pounds above the atmosphere. I think it has been very generally considered that the objection to using sea water for the "extra feed" at pressures of 150 lbs. arises from the more complete deposition of the calcic sulphate at those pressures than at pressures of 80 lbs. and thereabout. But this supposition is shown to be quite erroneous by Professor Lewes's statement that the whole of the calcic sulphate is deposited at so low a pressure as 55 lbs. Some different reasons must therefore be looked for to explain why sea water may not be used for making up the feed in boilers working at 160 lbs. pressure, whereas no evil results accompany its use at pressures of from 60 lbs. to 100 lbs. I hope what I have said may elicit a reply from Professor Lewes, or from some other member.

Mr. W. Parker (Member of Council) : I did not intend to speak on this paper, but it is a subject of very great interest—in fact, of the greatest interest—with regard to the maintenance of marine boilers. We have boilers now made that are unquestionably far superior pieces of workmanship than anything which has been made before, and they do not fail nor do they wear out in consequence of their being badly made, but because they are improperly treated, and it is the treatment of marine boilers which I think Professor Lewes has endeavoured to explain and has given us his views upon. It is frequently considered that solid matters, sulphate of lime, &c., are precipitated far more readily at high pressures than they were at the pressures of 60 to 70 lbs., which were in existence some ten years ago. And a great many engineers acknowledge that, instead of making the waste feed up from the sea, as was the usual practice with those moderately low pressures, it is absolutely necessary to have some means of distilling water and making up the waste by fresh. There are a great number of means of accomplishing this object ; there are distillers, such as those of Weiss of Glasgow, Kirkcaldy of London, and others that make large quantities of distilled water, some ten tons per day, at a very small cost indeed ; but there has been another arrangement introduced into a steamer for the purpose of evaporating salt water, which is so very simple I cannot resist explaining it. It is again, I may say, the introduction of our friend Dr. Kirk. In a steamer he built lately it occurred to him that if he could place in the funnel a large horizontal cylindrical vessel, and pump salt water into it, the waste gases

escaping up the funnel would evaporate that water, and give off sufficient steam to make up the extra supply required. He fitted this arrangement, and we had the means of measuring accurately the amount of extra feed required in an engine as far as possible in perfect working condition—that is to say, with no leakage except from glands, piston rods, and so forth. We found that the extra supply required, apart from all steam required for hot water purposes on deck, or blowing off, or anything of that sort, for the main engine alone amounted to one ton per 1,000 horse power per 24 hours, and this represents solid matter to the extent of ½ cwt. per 1,000 horse power per day. When this evaporator came back from a voyage to Australia, and was opened, I took from it a piece of solid matter, which perhaps would interest you. This is the little bit—it is quite 4 in. thick. The bottom of the cylindrical evaporator, which was 3 ft. in diameter and 16 ft. long, was covered with this deposit after running only ten days. Now, if that evaporator had not been there, nor a distiller, this deposit would have gone into the boiler, and I want to try and point out that it is in consequence of this scale, lime, or whatever we may call it, being allowed to get into the boilers that they do not last as long as they ought to do, and come to grief so rapidly. Professor Lewes does not advocate a distiller or evaporator. The arrangement which he has represented to us here, if I follow him rightly, is this: he places in a cylinder, or other formed vessel, a certain amount of water, and adds to it a certain amount of carbonate of soda. Then he applies steam for the purpose of heating the water, and when that water is heated to a temperature equal to 4 or 5 lbs. of steam, the solid matter drops down to the bottom of the receiver, and the water then passes away into the boiler with all the salt in solution. And he contends, which I have no right to object to, that that water going into the boiler with the salt in solution, will remain in solution until it reaches a density represented by the limit of saturation; that density, I think, is about 30 to 36 ounces to the gallon. If this can be done and worked out practically, I conceive a very great future for it. There are one or two points as to the mechanical details to which I wish to refer, and that would require modification. In the first place, in order to blow the water out he opens a cock from the sea. We know water will not run from the sea and blow out salt at any pressure above the pressure of the water. In my opinion this water would require to be pumped through these cocks. There are some other alterations in detail, that I will not refer to now. I really think the apparatus is worthy of the attention of marine engineers and shipowners, and that they should give it a trial.

Mr. W. H. White, F.R.S.: Sir John Hay and gentlemen, I know little about boiler incrustations, but I had the pleasure of seeing the fine specimen of "solid matter" just exhibited earlier in the day, and I was particularly anxious that Mr. Parker should not fail to produce it. I rise for the purpose of expressing how much we are indebted to a gentleman of the scientific standing of Mr. Lewes, who is the professor of chemistry to the Royal Naval College—for adding to his already heavy labours there and elsewhere in the cause of science such an investigation as he has made, and of which he has given us the results in his paper to-night with such practical suggestions for future experiment. I understand him to put at the disposal of the marine engineering profession his various suggestions; and I am quite sure I speak the sense of the meeting generally when I say that in numbering him amongst our Associates we feel that we are greatly honoured.

Professor V. B. Lewes (Associate): Sir John Hay and gentlemen, Mr. Thomas has asked whether if sea water is diluted to a density of 1·01 with distilled water, it will still deposit calcic sulphate when heated under pressure in a boiler. I have tried this experimentally, and find that even if sea water is diluted with a thousand times its own bulk of distilled water, the minute trace of calcic sulphate will separate in a thin pellicle, which attaches itself to the side of the vessel when a temperature of 300° F. or 149° C. is reached. Mr. Jones has raised the question as to whether there is not

some mistake in the pressure which I gave as necessary to deposit the calcic sulphate in the old forms of boilers working at a low pressure.

Mr. A. L. Jones: I did not say there would be no incrustation at 80 lbs., but that it would not be so excessive as to prohibit the boiler being worked by supplying the "extra feed" directly from the sea. A ship may run a two months' voyage, the boiler feed being made up in this way, with a resulting incrustation of perhaps a sixteenth of an inch in thickness, which does not seriously interfere with the efficient performance of the boiler, and it is not very apparent why the same system of working should not be equally applicable at the higher pressures of 150 or 160 lbs.

Professor V. B. Lewes: A temperature of 300° means a pressure of something like 72 lbs., and at this pressure all the calcic sulphate will separate out, although not so quickly perhaps as at a higher temperature. Calcic sulphate also continues to separate when once heated to the temperature at which the separation occurs, even after the pressure is removed, so that unless some secondary reaction takes place (of which I am totally ignorant, and to which the contents of the boiler give no clue), I should certainly expect all the calcic sulphate to be precipitated. That heavy deposits are formed at this and lower pressures, is shown by the specimens analysed and quoted in this paper, the *Northumberland's* boilers never having been worked above a pressure of 25 lbs., and the *White Swan's* at about 60 lbs. pressure. I am much obliged to Mr. Parker for the kind things he said of my paper, and also for bringing this huge block of deposit, which I see consists almost entirely of salt, and gives an idea of the troubles to be encountered in distilling sea water: of course such a deposit could not take place in a steam boiler, as the water would never be allowed to approach a density at which the salt would deposit in this way. As to the necessity of pumping sea water through the filter frames to clear the pores of the asbestos cloth from the precipitate, I am not sure that this would be an advantage: my idea is that the apparatus will be some feet below the level of the sea, and that this will give plenty of pressure to clean the frames without running the risk of bursting them; in any case, the cloth will have to be supported by a perforated metal plate on the side towards the hot well, and I should say ought also to have a wire gauze covering on the side nearest the apparatus. I have now only to thank you for the way in which you have received this paper, and to hope that by the next meeting I may be able to record some practical results arising from the trial of the method I have suggested.

The Chairman (Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S.): The thanks of the meeting have already been moved to Professor Lewes in the remarks made by our friend Mr. White, and I am sure that you will give them to him formally. We now adjourn until noon to-morrow.

AN APPARATUS FOR PROVIDING A STEADY PLATFORM FOR GUNS, &c., AT SEA.

By Beauchamp Tower, Esq., Member.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 12th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

I propose to describe an apparatus I have constructed and tried in practice, which gives a perfectly steady platform on board a ship in a seaway. There are probably many purposes to which such an apparatus could be usefully applied, but the purpose for which this particular machine has been specially designed is that of mounting a quick-firing or machine gun, or a search light or a telescope, on board ship, and especially on small vessels, the quick motion of which, even in a very moderate sea, renders these weapons and appliances almost useless.

I will first describe the construction of the apparatus by the aid of the diagrams.

Fig. 1 (Plate XXXII.) is a section through the apparatus showing the working parts.

Fig. 2 (Plate XXXIII.) is a plan looking down from above on the machine.

Fig. 3 (Plate XXXIV.) is a side view of the machine, showing generally how it is mounted on the vessel.

I will call the central part on which the gun is mounted, and to which the seat on which the man sits is attached, the "platform." This is, in fact, the part to be kept steady. This platform is suspended in gymbals on the top of a hopper-shaped pedestal, which stands on a round hollow pillar rising up from the vessel's deck. The part which, in ordinary gymbals, is usually a ring, has in the present case two opposite quarters of it cut away so as to form two gaps for the gun, so that the gun may lie exactly in the plane of the gymbals. Thus no disturbing effort is exerted on the apparatus by the force of the recoil. The remaining quarters of the gymbal ring are connected together rigidly by a half hoop, passing below and clear of the fittings of the platform. These two remaining portions of the gymbal ring are in the form of straight arms, and I will call

them the gymbal arms. These are well shown in Fig. 2. One end of each arm moves in a bearing attached to the top of the hopper-shaped pedestal, this bearing having all the motions of the ship; the other end forms a bearing in which the platform rests. These arms are made hollow, and the bearings contain water-tight oscillating joints, so that a supply of high-pressure water can be sent from a pumping engine through the hollow gymbal arms to the platform, for the purpose of actuating the mechanism which I am about to describe.

Projecting down from the platform and attached to it are four cylinders, one at each corner; out of the top of each of these cylinders projects a ram or plunger, which works freely, yet water-tight, in a collar at the top of the cylinder; each ram is attached by a connecting rod to the pedestal, and therefore to the ship. Supposing water under pressure to enter any one of the cylinders, it would press the ram out of the cylinder, and so cause the platform to be inclined in the gymbals. There being four cylinders equally spaced round the centre, the platform can, if desired, be inclined in any direction by forcing water into one or more of the cylinders. Connected to the bottoms of the cylinders is a cross-shaped frame. In the centre of this frame is a cup bearing, which forms the bearing of a heavy cast-iron disc wheel, revolving in a horizontal plane on a spherical journal resting in the cup, so that the wheel, while free to revolve, is also free to wobble through a small angle in any direction from the central vertical axis of the platform.

The centre of gravity of the wheel is placed a small distance below the centre of the spherical bearing. The bearing has a hole through its axis to form a passage for conveying high-pressure water into a cavity in the centre of the wheel. The presence of high-pressure water in this passage diminishes the friction of the bearing, by causing the greater part of the weight of the wheel to be carried on the water pressure; the wheel being made just heavy enough to hold itself down against the water pressure in the bearing. Water is in this manner supplied at a pressure of about 100 lbs. per square inch to the central cavity in the wheel, from whence it passes by two radial passages to two small tangential jets, the reaction of the water issuing from which causes the wheel to revolve with a velocity of about 1000 revolutions per minute. There is also an axial pipe leading up from the central cavity, and terminating in a jet nozzle $\frac{3}{8}$ in. in diameter and truly coaxial with the wheel. When the wheel is supplied with high-pressure water it begins to revolve, owing to the reaction of the tangential jets; if at starting it is not in a horizontal plane it begins to perform a slow conical movement, owing to the fact of its being suspended above its centre of gravity, the force of gravity therefore putting on it a couple tending to set it upright, and the wheel continually refusing to obey this couple, but inclining in a plane at right angles to it after the manner of a gyroscope, and thus causing the slow conical oscillation. This conical oscillation would continue unabated were it not for the friction of the spherical

bearing, which extinguishes this motion; and the wheel in a short time after it has started settles down to revolve in a truly horizontal plane with its axis truly vertical, and consequently throws a truly vertical jet out of the axial jet nozzle.

Immediately over this vertical $\frac{3}{8}$-in. jet, at a short distance from the nozzle, four pipes or passages terminate, with open ends pointing downwards. These open ends or ports are brought as closely together as possible; in fact, they are shaped so as to appear as a circle with two narrow bars crossing its centre, so as to divide it into four quadrants, each of which is one of the ports. (See Fig. 5, Plate XXXIV.) Each of these pipes communicates with one of the before-mentioned cylinders. The effect of the axial jet is to cause the cylinders to act so as to cant the platform until the centre of the axial jet is exactly opposite the centre of the circle of ports, that is to say, until the jet is equally distributed over the four ports, for if it is not in this position, the fact that one port gets more of the jet than another, causes the pressure in the cylinder with which that port communicates to be greater than the pressure in the other cylinders, and thus the platform is canted until the jet and the group of ports are concentric. Thus by means of the cylinders the platform is resolutely and powerfully held coaxial with the revolving wheel, and the plane of the wheel being horizontal, the platform is also horizontal. I wish particularly to draw attention to what I consider is a very important quality belonging to this combination. The platform assumes a horizontal attitude in obedience to the direction of the wheel, but at the same time there is no reaction whatever on the wheel tending to disturb it in its horizontal rotation, so the wheel acts powerfully on the platform, and yet suffers no reaction on itself. Whatever force is brought to disturb the horizontality of the platform, none of that force can disturb the horizontality of the wheel, as the wheel only acts on the platform through the jet, and what the jet strikes against after it has left the axial nozzle cannot in any way affect the wheel.

It will be observed that the platform must yield slightly to any force tending to disturb its centrality over the wheel, in order that the pressures in the cylinders may be so modified as to balance the disturbing force. The stiffness of the platform, or its power of resisting disturbing forces, can be regulated by varying the proportion between the areas of the cylinders and the length of the axial jet. There is, however, a limit to the amount of stiffness which can be given, owing to a tendency to oscillate showing itself if the platform is too stiff, but I have been able to make that of the present machine so stable that 300 lbs. on a lever one foot long causes an inclination of only one degree.

A man weighing 150 lbs. can move the centre of gravity of his body six inches on the seat, and only produce an alteration of level of one-fourth of a degree. The amount of error caused by the friction of the bearings and other mechanism is only about three-

quarters of a minute of arc. I should say that the man on the seat has under his control a valve governing a hydraulic training cylinder, by which he can turn the whole machine round in azimuth, so as to point in any direction.

I will now explain the theory of the modification of the pressure in the cylinders by the ports being more or less covered by the jet. It is easy for anyone familiar with an ordinary Giffard's injector to realise that a high velocity jet can penetrate a hole in a chamber against a considerable pressure. The late Mr. William Froude, in his address to the Mechanical Section of the British Association in 1875, showed that a jet of water issuing from a vessel under pressure, if received through a hole of its own diameter in another vessel, would very nearly reproduce in the receiving vessel its originating pressure (see Fig. 4, Plate XXXIV.). If there is no outlet from the receiving vessel the water of the jet is spilled at the receiving orifice, as the receiving vessel is full and will hold no more. If there is an outlet of the same size as the jet the whole of the water will issue through it with the same velocity as the jet and the pressure will be unaltered, but if this outlet is made larger than the jet the pressure will be diminished until it is no more than sufficient to give the water the diminished velocity proper to the enlarged orifice. Thus we can vary the pressure in the receiving vessel at will, from nothing up to nearly the original pressure of the jet, by varying the relative proportions of the escaping hole and jet. Now I consider that if a hole is only partly covered by a jet, that part which is covered must be regarded as a receiving hole and the uncovered part must be regarded as an escaping hole. The relative areas of these and the resulting pressures are, of course, rapidly varied by any motion of the jet.

I will now say a few words on the theory of the steadiness of the revolving wheel, on which, of course, the steadiness of the whole thing depends. It is clear that it is essential that the wheel shall keep its axis vertical to the horizon ; if it is at any other angle, any alteration of the ship's course will cause an alteration of elevation of the gun. I believe it has been attempted to obtain absolute fixity in space by means of a rapidly revolving and powerful gyroscope. But even if this were mechanically possible it will not answer the purpose, as a line perpendicular to the horizon is being continually inclined by the rotation of the earth, at a rate, near the equator, of a degree in every four minutes of time. It is therefore evident that the wheel must be made so as to obey gravity.

The late Mr. Froude in 1872, at which time I had the privilege of being one of his assistants, constructed an apparatus for automatically recording the rolling of a ship. For this purpose he hung in a vertical athwartship plane a heavy wheel resting on almost frictionless bearings, the centre of gravity of the wheel being only a small distance below the centre of suspension. This wheel, owing to its inertia, remained stationary while the ship rolled, and thus the angle of roll was recorded. This wheel was really a

very long period pendulum obeying gravity, but so slowly, owing to its great inertia, that the horizontal forces due to the wave motion could not sensibly disturb it during the short time they were acting in one direction. Now, my revolving wheel is really a long period pendulum ; its centre of suspension is but a small distance above its centre of gravity, and it is given rotation as a convenient way of giving it inertia, without making it inconveniently heavy and large. There is also the advantage that its revolution about its axis obliterates nearly all the friction which would otherwise tend to prevent it inclining freely in any direction. The relation between the speed of rotation and the distance between the centres of gravity and suspension is so adjusted, that the complete period of its conical oscillation round the true vertical is about $1\frac{1}{2}$ minutes.

The water used in working the apparatus I have described is about 50 gallons per minute. This water, after issuing from the jets under a pressure of 100 lbs. per square inch, falls into the hopper-shaped pedestal, and down the hollow column into a tank, from which the steam pump takes its suction. The water is thus used over and over again, but I know no reason why sea water should not be used, and, in vessels fitted with a fire service, the pressure from the fire-mains might be used to drive these machines. The engine which I have on board my yacht is an ordinary Worthington fire pump, which exerts, when the machine is in full work, about $3\frac{1}{2}$-horse power.

I will say a few words to illustrate the utility of this machine. I will put into figures what happens when my yacht is rolling through the very moderate angle of 10 degrees on each side of the vertical. Her complete period of rolling is four seconds, that is, she takes two seconds to roll from one side to the other, that is, through 20 degrees. This is a mean velocity of 10 degrees per second, and a maximum velocity in the middle of the roll of 15 degrees per second. Suppose a gun to be aimed at an object 300 yards off; the relative motion of the ship and the object aimed at will be the same as if the ship was steady and the object aimed at was flying upwards and downwards, through a distance of 314 feet, with a mean velocity of 107 miles an hour, and a maximum of 160 miles an hour. But in reality it would be easier to hit the object under these conditions than it is when the ship is moving and the object stationary, because the motion of the ship is continually disturbing the balance of the man's body; he has to hold on as well as aim. If the gun was mounted on the machine I have described, the motion of the object would be reduced to that due to the vertical rise and fall of the waves. This motion and velocity would in most cases be less than $\frac{1}{10}$ of the above figures, and I think there can be little doubt that the object would be much more easily and frequently hit, and that a ship with guns mounted on these machines would have a great advantage in an encounter in a seaway with a ship not so fitted, especially in these days of rapid fire, when one cannot afford to wait till the ship rolls to a convenient angle for firing. This apparatus will enable continuous

fire machine guns, such as the Maxim, to be used at sea, without wasting the greater part of their ammunition ; it should be also very convenient for mounting a search light or a powerful telescope. In short, it should enable many things to be used on a small vessel which can only effectively be used now on a large one.

I am not without hopes that it may also prove useful for diminishing the horrors of sea-sickness. It would be easy to make it control valves governing hydraulic cylinders, which would keep a swinging saloon, such as was fitted in the S.S. *Bessemer*, steady, the saloon obeying the motion of the platform, in the same kind of way as a steam steering engine follows the hand of the steersman. Such an arrangement would use less power than would be used if the saloon was steadied directly by jets, but I think that, though sufficiently accurate for this purpose, it would probably not be sufficiently so for guns. As far as my own personal experience goes, the effect of the apparatus in doing away with the inconvenience of the ship's motion is very marked. The sensation of calmly sitting on the machine at one's ease, and seeing the ship roll about under one and everybody else holding on, is a very novel one.

DISCUSSION.

Mr. H. M. Brunel (Visitor) : My Lord, I should like to describe my experience of this machine. I went out with Mr. Tower in his yacht to near the *Warner* lightship. There was a fresh easterly breeze, quite enough to give sufficient motion to test the machine. The vessel is 50 feet long, and of the dimensions indicated on the cross section, Fig. 3, whereon the man is drawn to scale. I went on the machine twice ; once for five minutes, and another time for a quarter of an hour. The sense of steadiness, described by Mr. Tower, I found to be most remarkable ; one forgot that one was on board a ship. I was looking along the sights of the wooden gun that is mounted on the apparatus, and my feeling was one of disappointment that the ship was not rolling much ; and then, on looking at the rolling batten, I found that the vesssel was rolling through an out-to-out arc of 20 degrees. While I was on the machine Mr. Froude noted an out-to-out roll of 30 degrees. With regard to the accuracy of the machine, when looking along the sights I noticed a slight change of direction, of, perhaps, half a degree, which could be corrected by the elevating screw. Mr. Tower informed me that this error was due to a defect in the rotating bearing, which could easily be remedied. The effect is very startling, of sitting level and at ease, and seeing the vessel tumbling about beneath one, and the other people having to hold on. I quite believe in the success of the instrument, and with regard to the last point mentioned by Mr. Tower—namely, sea-sickness, on which I am an expert—it seemed to me to be a very great thing to get rid of the rotative movement, even though one cannot get rid of the up-and-down movement.

Mr. R. E. Froude (Associate Member of Council) : I rise, my Lord, to corroborate what Mr. Brunel has said as regards the accuracy of the working of this instrument. The paper explains the principle of operation so clearly that I think if I were to attempt to add any explanation or description of my own, I should perhaps make it confused rather than more clear. I would only say that, as far as I can see, the principles of operation are perfectly sound. It is one thing to devise an instrument on

correct principles, but it is another to carry them out as successfully as Mr. Tower has done. The action of the gyroscope in this instance is closely analogous to the action of a governor in controlling the speed of an engine, and anybody who has ever tried it knows what a difficult thing it is to make a steam governor which will act with real sensitiveness and at the same time shall act steadily. As regards the performance of the instrument, I was present on the same occasion as Mr. Brunel, and also on another occasion with Mr. Tower alone, and on both occasions I sat on the instrument. I should express my experience in this way. There was a little rapid vibration of perhaps about a second period, which very seldom exceeded $\frac{1}{4}$ of a degree range, and often for a long time it would be absent altogether. Besides that, there was a very slow crawl—a wandering—which seldom exceeded a degree. When it did exceed a degree was when the gyroscope was diminished in speed by the circumstance which Mr. Brunel has alluded to, and which Mr. Tower will perhaps explain more fully. Even at the worst, that slow motion was one that could be perfectly well corrected by the elevator screw; and although to follow the motion by means of a screw of that kind is an operation which of course requires a certain amount of practice, even without any practice I was able nearly always to keep the gun pointed within the amount of the small vibration which I have described, and which very seldom exceeded the fifth of a degree. There is one thing I may refer to which has been suggested to me by Mr. White. He asked about the way the gyroscope steadies its vertical axis. It does not, of course, start vertical, because the ship is rolling about, and while the operator is getting on to the instrument, the instrument has to be locked, and necessarily rolls with the ship. At the moment when the steam is turned on, and the jet begins to act, the instrument is in some casual position, out of the upright, and the effect then is very much like the steadying of a top. In my recollection it takes about a minute to get it perfectly steady.

Mr. Macfarlane Gray (Member of Council): My Lord, I would like it to be understood that I wish to compliment the inventor as highly as words can praise the ingenuity and skill which he has exhibited in the construction of this apparatus. In 1874 I was the first to point out the fallacy in the construction of the apparatus which had then been made for controlling the motion of a large swinging saloon on board a passenger steamer. In the apparatus now exhibited there is no error in interpreting the dynamical principles of the gyroscope. In 1874 I patented an improvement in gyroscoping controlling gear, to remedy the error to which I had drawn public attention. A working model of the arrangement proposed by me was exhibited in action on board the steamer on a trial trip, and it then gave so much satisfaction that the original designer of the swinging saloon made, with me, a preliminary arrangement for applying my method to the already constructed swinging saloon. This intention was not carried out, but that was not due to any question about the soundness of the plan I proposed. On page 349 the author states clearly the steadying principle of the gyroscope, which has been so often overlooked. Until I drew attention to it in 1874 there were very few engineers who did not firmly believe that a rotating disc tends to maintain its plane of rotation. I could not get any of my mechanical friends to believe the opposite until I had a gyroscope fitted to show the true action. There was a pinching pin on the vertical socket, so that the stalk of the gyroscope frame could be gripped, and the rotation of the frame in azimuth prevented. When so gripped, the rotating gyroscope offers no resistance to change of plane. It can by a slight impulse be made to rotate transversely to the proper rotation of the disc. When the pinching pin is turned back, the transverse rotation instantly ceases, and the rotating disc has simultaneously its apparent property of steadiness restored. What I proposed then was to control the swinging of the saloon about one horizontal axis, the fore and aft axis in the steamer. That was to be done by mounting a horizontal rotating disc upon a frame suspended on transverse knife-edge trunnions, which

partook of the motion to be corrected. If the pinching motion had also to be corrected, so as to get a *level* platform, that would have required another similar gyroscope, with its frame bearing set fore and aft. This brings my remarks now to what Mr. Tower has done. He accomplishes the level platform feat with only one rotating disc. That he has made with a knuckle bearing and perforated arms, and a beautifully contrived self-directing nozzle, which, for compactness and ingenuity, and the serving a double purpose, seem all to be more akin to animal organism than to anything else in the mechanical kingdom. I heartily sympathise with the inventor in his trouble over finding a satisfactory material for the ball bearing. Gearing and dynamical effects can be designed with certainty of mechanical result, but often the new combination creates a physical problem far more difficult to solve. I am sure Mr. Tower has the best wishes of every member of this Institution for the complete success of his bold and interesting undertaking.

Captain S. Long, R.N. (Associate) : My Lord Ravensworth and gentlemen, I did not come here to-day expecting to hear that Britannia, in the person of Mr. Tower, had managed to rule the waves straight, and I can only hope that he will succeed in doing so. In an invention of this kind there are two aspects. You may either criticise the invention, or point out whether it is likely to be useful if it succeeds. I do not feel at all equal to criticising the invention, but I should be very glad to point out, as a naval officer, that if it can be made successful, it will exercise a very important influence on naval warfare, because no doubt the great errors that are made in firing guns are those due to elevation, and that is more especially true now that the guns of the present day have such an exceedingly flat trajectory. If you were only certain that you could have your gun horizontal at the moment of firing, you might be certain of hitting anything within 2,000 yards. I think that is a point which makes any invention of this kind well worthy of trial. I should like to ask Mr. Tower if, in his reply, he would mention the cost of fitting it for such purposes?

Mr. B. Tower (Member) : I think you do not quite understand. This is actually fitted on board my steam yacht; and a machine large enough, I believe, to mount a three-pounder is actually in existence, and has been tried. Mr. Froude and Mr. Brunel have both related their experience on it. The drawing on Plate XXXIV. is an actual drawing of the machine to scale, half size, with a mid-ship section of the yacht, with the man, and everything.

Captain S. Long, R.N.: I understand it has been tried, but sometimes things are tried by amateurs, who are not afraid to lay out disproportionate sums of money on them, and they are not considered of practical value afterwards, on account of the enormous expense involved in fitting them. I should like to know whether it would be a very expensive thing to try a gun mounted on that principle, because I think it would be well worth doing, if the cost is not prohibitive.

Captain C. Penrose FitzGerald, R.N. (Associate) : My Lord and gentlemen, I had not intended to speak on this paper. I feel quite incompetent to criticise the machine in the very short time which I have had to look at its action. Of course, we take Mr. Tower's assurance, and Mr. Brunel's, and Mr. Froude's, that it works, and does steady a platform. The idea of using the gyroscopic action in steadying a platform is not altogether new. If I may be allowed to say so, with all respect, I wrote myself about fourteen years ago to the late Mr. Froude, and suggested that a gyroscope should be used to steady a gun platform; and he was kind enough to write me a long letter, in which he explained the fallacy which Mr. Macfarlane Gray put before us in such striking and graphic language. The fact was that when you wanted to pull it one way it was not an absolutely steadying motion, but what it did was to drive itself at right angles another way. If you

pulled it a degree down here, it would insist on taking a sort of rocking motion. It is difficult to explain oneself in popular language; but what I mean is, that it would take a degree out of you some other way—go down on the other side, not on the opposite side, but at right angles to the motion, and, therefore, you did not get an absolutely steadying motion. I confess that I do not understand the gyroscopic action of that machine that produces the steadying effect—it is used in another way, I suppose. I feel entirely incompetent to discuss it, but it would be most interesting to us if we could get as Naval officers a steady gun platform. It is an old saying, that if you can hit the enemy you stop him from hitting you. If he is rolling anything like what is shown in that diagram, and your gun is steady, then he will not have a chance of hitting you, but you would be able easily to hit him. As to its application for preventing sea sickness, I am a little sceptical; and although I do not happen to be a great connoisseur in that particular, like Mr. Brunel, still I should be very glad to see our friends and relatives when they are crossing the Channel safe from its horrors, but I do not quite see how that is to be done. I do not suppose you would hoist all the passengers in the Channel steamers, ladies and all, up into that position. I think certainly the ladies would object to it, even if they were told they were not going to be sea-sick. It is a most interesting paper, and I hope the invention will receive that support of which it seems to be deserving. It would be of real practical value for guns, and also for the electric light, which Captain Long did not touch on. We are told that in blockading we are to be surrounded by a cordon of electric lights placed in the four quarters. These are to be carried in small ships, which are to be comparatively cheap ships, as Sir Nathaniel Barnaby describes his, and you would not mind if they were sunk—he would not mind, at any rate. These cheap ships would be small, and therefore would roll; but if you could put the electric light, mounted on that principle, in four of Sir Nathaniel Barnaby's cheap ships, you would have arrived at a point of enormous value in protecting ships from torpedo attack; the advantage would be almost invaluable to the blockading force, and consequently, I suppose, to our Navy.

Mr. Macfarlane Gray: My Lord, just a word in explanation, because I have been misunderstood as having condemned it, and as if I were saying that the gyroscope principle was a fallacy, and was put out of Mr. Bessemer's steamer. So far from its being a fallacy, I pointed out in 1874 the principle of acting by the steam-engine valve and putting the gyroscope the proper way.

Admiral Sir John Hay, K.C.B., D.C.L., F.R.S. (Vice-President): My Lord, I would say one word upon this subject, because although I do not wish for a moment to challenge the ingenuity or the practicability of Mr. Tower's invention as regards Naval gunnery, I do not conceive that it would be of any special value to us. It seems to me that the training of a Naval gunner is this: to do that which we all may understand by saying that he has to shoot flying. It is true that Mr. Tower's proposal would eliminate one of the difficulties, but only one. You have to teach the captain of your gun to fire his gun, making allowance for the change in the direction of the object at the time the shot would reach it. That is one consideration. You have also to teach him to recollect that after he has pulled the trigger, and the charge is ignited, there is a certain arc which the muzzle of the gun is passing through while the shot is traversing the bore. All these various considerations have to be present in his mind, and when he is an experienced gunner he makes allowances for all these various circumstances, and his shot will eventually attain the moving object from the moving gun which he has discharged. I do not believe that eliminating one of the difficulties would increase his attention to the other difficulties. I believe that it is better that the Naval gunner should simply and directly be taught to discharge his gun considering all the various contingencies of the movement of the muzzle through the arc during the time the shot is passing down the barrel, and the change of position of the ship

and the change in the position of the object at that time, both due to the sea and her motion, which will enable him, if he gives due consideration to all these subjects, to attain the object, which is to hit his mark; and therefore, however valuable it may be for telescopes and other objects, I do not myself believe that it will be worth the trouble of erecting in Her Majesty's ships for giving more accuracy to gun-fire.

Mr. David Joy (Member): My Lord and gentlemen, some years ago I tried to work in this direction myself, more for pleasure than for profit, and as I have also had the pleasure and advantage of seeing Mr. Tower's machine, I think, perhaps, I may say a word or two on the subject. After I read Mr. Tower's paper, and having an engagement at Southsea, I wrote to Mr. Tower to ask if I could see his machine, and with extreme courtesy he made arrangements for me to meet him on board. To my disadvantage I found that the machine was in pieces, but Mr. Tower was there himself to explain it; and so I got a pretty good notion, not only of the whole machine itself, but of the methods which Mr. Tower had applied to gain the object which I myself before had attempted, but only attempted. Mr. Tower further very kindly invited me to go with him the next day. I believe it was the visit when Mr. Brunel was present on the boat. Unfortunately, I had to leave that part of the business, and I never saw the experiments; but from my examination of the machine, and the experience I had in trying to accomplish the same end, I came to a most perfectly clear decision that that machine would answer precisely the ends which Mr. Tower had in view; and though it would be very vain in me to differ from so great an authority as Sir John Hay, still I do think that with so perfect a result as is to be got by that machine, that a very large amount of the trouble of firing guns would be removed. Perhaps, if your Lordship does not think it irrelevant, I might say what it was that I attempted some years ago in that direction, and how it bears upon this subject. It came about in this way. It was suggested to me by a gentleman who had nothing to do with war, and would not have had anything to do with it on any account, to scheme a gun with a smooth bore to carry an elongated shot, which would fly straight by spinning on its axis like a rifled shot, and the idea was to revolve the gun. I designed the gun, and then found that by going a step further, and putting a wheel or ring round it, and mounting the whole in gimbals, I had a gyroscope, and the gun itself revolving on its centre, that such a gun would fire precisely like a rifled gun, and would also keep its centre line of fire. Further, I was much encouraged to proceed in my experiment in this direction by reading of a similar and very interesting experiment in a book by Professor Piazzi Smith. Mr. Macfarlane Gray and I discussed this the other day. The experiment was this, that the Professor, wishing to take astronomical observations at sea, mounted a telescope on a gyroscopic table, and was thus enabled to keep the horizon, or any star near it, in the field of the telescope, although the whole machine was mounted at the stern of the yacht, the most unsteady position possible.

Mr. Macfarlane Gray: Two gyroscopes at right angles, because one would not do.

Mr. D. Joy: Only one gyroscope is mentioned in the description, and the size and weight of the wheel are given as 12 in. diameter and 11 lbs. weight. In my experiments I used a 5-in. wheel, with a bar representing the gun; this I mounted in gimbals, and then fastened the whole on the middle seat of an ordinary rowing boat, and, cruising in the Walney Channel, outside Barrow-in-Furness, I found no difficulty in getting motion enough to test my machine. The result was that though I could mostly obtain a steady centre line for my representative gun in a fairly horizontal position—and this was adjustable within reasonable limits by a slight and steady pressure—any attempt to shift the position of the gun caused such a reaction that the whole machine was all

over the place in a moment—that while I got some result, it was not what I could rely on. And it is just this which, from my examination of Mr. Tower's machine, I was led to believe he had arrived at.

Mr. Wingfield (Visitor): My Lord, and gentlemen, I have nothing but admiration to express for the really beautiful way in which this problem of utilising the directive force of a gyroscope has been worked out. I made some experiments in a similar direction, and met with many difficulties which quite baffled me at the time; but here I think they have been successfully overcome—the hydraulic attachment, or rather non-attachment, is a wonderfully simple and beautifully effective device. But there is one point I would call attention to—not the mechanical part, which appears to be perfect, but the shooting. Of course a certain amount of elevation has to be given to the sights of a gun to make the shot cover the range, so that the bore of the gun does not point directly at the object, but above it. What I am about to say would apply in any case, but especially if, as in the apparatus shown, the gimbals are not put at right angles to the gun. To take an extreme case, if a ship rolled over to a very large angle, so that the gimbal went over, say 90°, the gun, if kept sighted at the object without being allowed to rotate on its pedestal, would rotate on its own axis to very nearly the same amount, and the result of this would be that the barrel of the gun would point, not above the object, but to one side of it, and though, of course, the angles would be very slight—Naval officers will be able to say how much—that would affect the shooting. The gunner would have to allow for that error, and it would be a constantly varying quantity. If no adjustment is made, except the automatic one described, the gun will not rotate on its own axis, but will move from side to side as the ship rolls, producing the same effect on the shooting as that described above. I notice the author mentions hydraulic arrangements for swivelling the gun on the pedestal. These, no doubt, are requisite to enable the gunner to correct these errors. I think it would be possible to make this adjustment automatic.

Mr. W. H. White, F.R.S. (Vice-President): My Lord, may I be permitted to say one word? I shall be very short. Mr. Froude just now alluded to a difficulty I had expressed to him, as to one matter affecting the principle of this invention. I perfectly understand that the instrument would secure the movement of the gun in parallel planes; but what I did not understand, and even now do not clearly understand—although I am familiar with the problem of the spinning-top—is how, in a moving ship at sea, this wheel does necessarily produce the exact and true horizontal. That is my point. I have no doubt Mr. Tower will explain it when he replies; and, if he does, he will be conferring very great benefit on others besides myself. The problem of the application of this instrument to Naval gunnery is chiefly one for Naval officers; but it is obvious that the difficulty of making accurate shooting in a seaway arises from both rolling and heaving motions. Heaving must go on (as Mr. Brunel has pathetically observed); but I understand, as might be anticipated, that the movement of the ship in heaving is not nearly such a disturbance to good shooting as the rolling. What Mr. Tower has done in his yacht for small guns shows, therefore, how the greater of the two evils which exist may be cured. But, besides this, there are many applications of the principle possible. There is one obvious application which, if the wheel really assumes the true horizontal, would be, I think, of almost inestimable value—namely, the determination of the rolling of a ship. Observations are continually reported of the rolling of Her Majesty's ships, and one of the greatest difficulties met with, especially under the circumstances of very heavy and thick weather, where horizon observations cannot be made, is to know what is the true rolling of the ship. Pendulum observations are often sent to us, which are the best that can be made under the circumstances, and there are endless

instruments dependent for their action on the directive force of gravity; but they are all liable to the same error. The result is that we often get recorded angles of roll which are clearly not admissible, and cannot have happened. An instrument of the nature proposed by Mr. Tower, if the wheel does really assume the horizontal as its position of rest, would therefore be of the greatest possible value. I am sure that all of us admire the wonderful ingenuity which has been displayed in securing this directive force without reaction, which is one of the difficulties which Mr. Macfarlane Gray dwelt upon at the time when the *Bessemer* saloon was being constructed, and it was proposed to use the gyroscope to control and keep horizontal the saloon. This paper gives us another proof of what we are all so familiar with—namely, that Mr. Tower is one of our most able mechanicians.

Mr. J. H. Heck (Member): My Lord, just one suggestion. If by this arrangement a platform can be kept in a horizontal position at sea, there is one adaptation which I think might be useful in the firing of big guns, for in place of mounting the gun on the platform itself, by a little modification, an arrangement could be made by which the gun could be automatically fired off, either in a horizontal position, or at any angle of elevation or depression; and I believe that if Mr. Tower would devote a little time to this question, some useful outcome would be the result. The cost of firing big naval guns is, of course, great, and I have often felt that, through economical reasons, the amount of practice with such guns is not quite so much as it should be. I believe experiments were made some years ago at Portsmouth for automatically firing off guns when in a certain position by means of a pendulum. A pendulum is, however, of course, more or less affected in its action by the motion of a vessel when at sea. If this is not the case with the instrument now under notice, then I think it could be made useful in the direction indicated. I have only to express the very great pleasure which I have derived from the most interesting paper which Mr. Tower has read, and for the experiments which he has made with reference to this matter.

Mr. B. Tower (Member): My Lord, I shall not occupy very long in what I have to say in reply. With regard to Mr. Brunel's experience about the half-degree error, I would first explain to the meeting that at the time he came to see the machine I was experimenting with a variation in the construction of this spherical bearing, and I had, unfortunately, tried a bell-metal ball in a phosphor bronze cup, which turned out to be a most unfortunate combination of materials. The bearing was continually heating, and I had to keep on continually oiling it. I believe it seized three or four times, and the machine actually stopped from the fact that the bell metal was continually abraiding the phosphor bronze cup. I found that the oil which came away from it was completely charged with brass. I have been experimenting with this apparatus for the last eight months, and have been continually varying the proportions and materials of the parts, in order to obtain the best possible results; for, of course, the details of a new thing like this can only be perfected by a process of evolution, a process of trial and error, and the survival of the fittest. I have tried, amongst other things, a vulcanite ball resting in a bronze cup. This answered admirably for a time, and I can assure you that while it was in good order the machine kept its zero perfectly, but, unfortunately, the vulcanite did not last long, and frequently had to be renewed. I am now trying a hard cast-iron ball, resting in a hard cast-iron cup, and I believe that, if it is lubricated well, will work all right. That is what I have here. I am also going to try a steel ball, resting in phosphor bronze. It is a mere matter of trial to find out what are the best materials, and I am sure that slight error of half a degree, which Mr. Brunel and Mr. Froude observed, was due to a defect of the bearing which can be remedied. My own experience of the machine, when in good order, with regard to the error is this: that, with a roll of about ten or twelve degrees, there is no perceptible error at all; but if my yacht, which has rather a quick period, rolls up to fifteen or twenty degrees, there is an error of about

one quarter of a degree, that is all, and that is really a very small quantity compared with the total rolling of the ship; and it must be borne in mind that if this same machine were mounted in a larger vessel—my yacht is only 11 feet beam and 50 feet long—that the larger vessel would roll more slowly, and there would be the same accuracy with fifteen degrees or twenty degrees as there is now with my yacht with a roll of ten degrees. With regard to Mr. Macfarlane Gray's remarks about the gyroscope, it is very simply shown here. Supposing this is spinning rapidly, going round in that direction—if you try to push it over, so, it will not go this way, but it will go that way—at right angles to the direction in which you push it. The effect of the thing rotating rapidly is only to give it practically an increased inertia—that is, if it is perfectly free to change its axial direction. It really has no fixity of itself. Any force you put on the gyroscope to disturb it, it does not matter how small the force is, will disturb it, and make it incline in a direction at right angles to the force. So that if you attempt to use the gyroscope directly, you would have, first of all, to balance everything perfectly—you would have to adjust the balance weights so as to balance the man perfectly, otherwise there would be a small force always tending to disturb it; but the function of this arrangement is to correct any want of balance, and, as a matter of fact, the man, when he is on the seat, can take up a weight of 20 or 30 lbs. in his hand, and put it down, and practically cause no disturbance. In answer to Captain Long, I may say that the only actual firing trials I have had with this machine were with a half-inch Winchester express rifle. The effect is certainly wonderful. You have only to try firing the rifle from the machine at an object, and then from the ship's deck, to be convinced of the value of the thing. No one who has once tried it could doubt for a moment as to what would be the result of a shooting match between two men, one on the machine, and the other on deck, and subject to all the angular motions of the ship. While on this point I will reply to Sir John Hay. I can only say that I am quite willing to back myself against the best shot he can bring forward, and see who will make the best shooting: his man, with all the admirable skill he speaks of—and certainly it is most admirable in consequence of the great trouble which must have been taken to acquire it—or myself, on the machine. I can quite understand his feeling of sorrow that so much skill should be rendered unnecessary, but at the same time we must bear in mind that some day there will be a shooting match in which the stake will be an Empire, and we must not allow a sentimental affection for skill, no matter how admirable, to prevent our providing the best means to enable the men on our side to hit the target most often. As a proof that the trained skill of the gunners is not effective against rolling, I must refer you to the report of the Committee on the last year's Naval manœuvres of H.M.S. *Arethusa*. They say, "on account of her quick and heavy rolling, accurate shooting would be an impossibility, and the machine guns in the tops would be useless." The *Archer* class are described as "unsteady gun platforms." Of the *Rattlesnake* class, they say "the gun platform is, as may be expected, an unsteady one, except when nearly calm, and it is on all sides reported that the 4-inch gun could not be fought in a seaway." Now, with regard to the electric light. It came to my knowledge, owing to the fact that some of Her Majesty's torpedo boats were fitted with the electric light, driven by an engine which I brought out, that it was found perfectly impossible for any man to keep the search light on an object in anything of a seaway, that the light was under these circumstances perfectly useless, and I thought that something might be done in this direction, and it was that which drew my attention to the importance of designing a thing of this sort.

Captain C. Penrose Fitzgerald, R.N.: That is a gun that is constantly firing.

Mr. B. Tower: Yes, no doubt. I should explain that the method by which I have observed the accuracy of the machine, and by which method Mr. Brunel and Mr. Froude observed it, was with a

Quaker, a wooden dummy gun. This is shown on that drawing ; there are two sights, the back sight is provided with a hole, about $\frac{1}{4}$-inch diameter, through which the observer looks at the foresight, which is provided with a batten, which is marked in degrees. You get this against the horizon. Close alongside this there is a batten fixed in the rigging of the yacht. When you look through the hole, you see the scale on the foresight stationary against the horizon, while that on the batten in the rigging is moving up and down with the vessel's motion. So that thus you can easily compare the steadiness of the machine with that of the vessel, and see exactly what it amounts to. With regard to what Mr. White said, I am not quite sure whether I understood him, but I should explain that the gyroscope naturally steadies itself and keeps to the horizontal plane. I should say that Mr. Froude, when he had to contrive an automatic machine for recording the rolling of ships, constructed two pendulums. One was a very short period pendulum, which hung perpendicular to the wave slope, and he also had a very long pendulum of about 70 seconds. The period was so different to that of the waves that it was not affected by the horizontal forces due to the waves. That is exactly what I have done here. This is really a pendulum. It is hung above its centre of gravity, so that gravity is always pulling at it, and if it starts out of the horizontal it goes through a conical movement for a short time, which gradually dies out, and then it comes to the true horizontal plane. It would be very easy indeed for a machine like this, fitted on board a ship, to be connected with a recording apparatus so as to give a correct diagram of the rolling of the ship at any time, and I have no doubt it would give such results very accurately. I do not think I have anything more to say.

The PRESIDENT: Gentlemen, I am sure you would wish me to convey your thanks and congratulations to Mr. Tower for the very admirable and clear explanation which he has given of this most ingenious apparatus. I think there has been a general consensus of opinion as to the extreme nicety and beauty of the apparatus itself, and the great ingenuity exercised in its construction. I think that that goes without saying, and that everybody is agreed in that. As to the applicability of this for comparatively heavy ordnance, only time and experience can show that, but I am sure at the same time you will wish me to convey your most hearty thanks to the author of the paper, and to those gentlemen who have brought so much intelligence to bear on the discussion, which has been of a very practical and admirable character, as I think you will all agree.

THE CORROSION AND FOULING OF STEEL AND IRON SHIPS.

By Professor V. B. Lewes, F.C.S., F.I.C., Royal Naval College, Associate.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 12th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The difficulty of obtaining adequate experimental data, and the fact that nearly everyone who has worked at the subject has had a composition of his own to bring before the public, has so hampered and restrained the free discussion and interchange of ideas on this most important question, that at the present time we have made but scant progress beyond the point reached twenty years ago, and my object in bringing this paper before you is more to excite you to discussion, and to show you the known facts of the case, than to tell you of any very new or startling discoveries.

Corrosion generally precedes fouling on exposed metal surfaces, and it is therefore this portion of the subject that will be considered first, together with the means which have been taken to prevent it, and to protect the plates of our vessels from decay.

In a paper which I had the honour to bring before you two years ago, I pointed out that in all processes of rusting carbonic acid gas and moisture played an important part, the iron uniting with the carbonic acid and oxygen of the water to form ferrous carbonate whilst the hydrogen was set free, and that the ferrous carbonate then took up oxygen dissolved in the water, or present in the atmosphere as the case may be, and was decomposed into ferric oxide (rust) and carbonic acid, which being liberated in actual contact with the moist surface of the iron carried on the process of "rusting."

This view of the case was confirmed by a paper read by Professor Crum Brown before the Iron and Steel Institute, at Edinburgh, last autumn, and is generally accepted as the true explanation of the corrosion taking place on iron or steel surfaces exposed to moist air or fresh water; but the rusting of the metal in sea water has by many chemists been ascribed to a more complex action, in which the salt present plays an important part by first forming oxychloride of iron.

This preliminary stage of corrosion in sea water is, I am inclined to think, a myth.

When iron filings or turnings are exposed to the action of sea water, hydrogen gas is evolved, and ferrous oxide and carbonate are formed, and this changes, as in air or fresh water, into ferric oxide, by taking up dissolved oxygen present in the water. At no time have I been able to detect the presence of oxychloride, and from the fact that a few drops of alkali added to the sea water stop the corrosion, I am of opinion that the simple rusting of iron in sea water is due to the same cause as in fresh—*i.e.*, the decomposition of the water by the iron in presence of carbonic acid.

The saline constituents of sea water, however, do undoubtedly play an important part in a more active form of corrosion, by helping to excite galvanic action between the iron in the plates and any foreign metal or impurities present; an action which is also materially aided by want of homogeneity in the metal, by particles of rust, by mill scale, by wrought and cast iron or steel in contact with each other; or even by the different amount of work, such as hammering or bending, undergone by different parts of the same plate; and in all of these cases the galvanic action set up causes rapid oxidation of the iron at the expense of the oxygen of the water, hydrogen being evolved.

We may therefore consider that on the skin of a ship two processes of rusting are going on: the one, simple corrosion on exposed surfaces of the metal, due to the presence of moisture, carbonic acid and free oxygen, which forms a fairly uniform coating of rust on the metal; and the more local corrosion due to galvanic action, which results in pitting and uneven eating away of the plates.

As I pointed out in my previous paper, rust cones are due to the most local form of galvanic action, caused by the presence of a spec of deposited copper, lead, or other foreign metal, or even a small particle of rust, or mill scale, left on the surface of the iron, and covered by the compositions used as protectives and anti-foulers; as soon as the sea water penetrates to these, galvanic action is set up, water is decomposed, rust formed, and the escaping hydrogen pushes up the composition, forming a blister, the hydrogen leaks out, and water leaks in, the action becoming more and more rapid, and the blister gradually filling with the result of the action—rust. The blister bursts, but the cone of rust has by this time set fairly hard, and continues to grow from the base, the layers of rust being perfectly visible in a well-formed cone, and when the rust cone is detached, the pitting of the metal at the base of the cone is, as a rule, found to be of considerable depth.

The speck of foreign matter which has caused this destructive action generally clings to the surface of the iron, and, being at the bottom of the pitting, escapes detection and removal, and when the vessel, newly coated with fresh compositions, again goes to sea, the corrosion will again probably be set up in the same spot.

The corrosion of the plates in the interior of a vessel is a subject quite equal in importance to the external action of sea water and dissolved gases on the metal; and from the fact that certain portions of the interior plates, from their position, escape the frequent examination and attention bestowed upon the exterior, it becomes a still greater source of danger.

Corrosion, like all other forms of chemical action, is much accelerated by increase of temperature; and in the bottom of a ship, near the furnace-room and boilers, this has a considerable effect in increasing the rapidity of rusting. Also in the coal bunkers, the mere contact of moist coal with the iron plates sets up galvanic action, carbon being electro-negative to iron, and the coal dust which sifts down into the double bottoms lends its aid to the destruction of the plates; whilst, if the coal contains any "pyrites," which is nearly always the case, these double sulphides of iron and copper are gradually oxidised into soluble sulphates of the metals, and these, washing down into the bilge water, would at once cause most serious corrosion, should they come in contact with any bare portion of the plates. Repairs to any portion of the inside plates will loosen rust and mill scale, which, finding its way into the bottom, tends to set up galvanic action; whilst the scale of oxide of copper from copper and brass fittings and pipes is another great cause of danger, as the bilge water would gradually convert it into soluble salts, which will deposit their copper upon the iron wherever a crack or abrasion enables them to come in contact with it; and finally, leakages from stores and cargo are in many cases of a character highly injurious to iron.

In addition to all these sources of danger, we must remember that the interior of the vessel is the part most liable to abrasion from shifting and moving of cargo, coals, &c.

The protection of the outsides of the bottoms of our ships from the destructive agencies of sea water and dissolved gases may be said to have been attempted in two ways, by metallic and by non-metallic coatings.

So far, all attempts at metallic coatings have proved failures, and, as far as it is possible to judge, there is but small likelihood of their ever being made to succeed, because if zinc is used in order to protect the iron of the ship there must be galvanic action, and this action must take place evenly all over the surface of the zinc plates, which means that the sheathing must be in uniform metallic contact with the iron, in which case the wasting of the sheathing would be so rapid that it would have to be frequently renewed, which, even leaving out the question of cost, is in many cases impossible.

Zinc is practically the only metal which could be used for this purpose, in order to place the plates of the ship in an electro-negative condition, and it is, therefore, to zinc that inventors have turned from time to time, the chief novelties introduced being the method of attachment. As far back as the year 1835, I believe, Mr. Peacock tried zinc plates on the bottom of H.M.S. *Medea*, and in 1867 Mr. T. B. Daft again brought the subject forward; Sir Nathaniel Barnaby, Mr. McIntyre, and others, also suggesting various plans of attachment, whilst as late as last year Mr. C. F. Henwood read a paper at the United Service Institute again strongly advocating zinc sheathing as attached by his system.

Where the galvanic contact has been but small there the sheathing has had a certain life, but has afforded but little protection to the iron, and has gradually decayed away in a very uneven fashion; whilst in those cases where galvanic contact has been successfully made the ship has on several occasions returned from her voyage minus a considerable portion of the sheathing.

Another drawback to the use of zinc sheathing is one which was found when it was used to coat wooden ships, and that is that zinc when in sheets, like every other metal, is by no means homogeneous, and that for this reason the action of sea water upon it, leaving out of consideration galvanic action, is very unevenly carried on, the sheathing showing a strong tendency to be eaten away in patches, whilst the metal itself undergoes some physical change, and rapidly becomes brittle.

Attempts have been made to galvanise the iron before the building of the ship; but Mr. Mallet showed as early as 1843 that this coating was useless when exposed to sea water, as in from two to three months the whole of the zinc was converted into chloride and oxide, and that when, therefore, galvanising is used, care must be taken to protect the thin coating of zinc. This does not, of course, apply to fresh water, in which galvanised iron would answer very well, the rapid action being due to the salts in the sea water; but even in this case the galvanising would have to be done after the plates had been riveted together, as any breaking of the surface would set up rapid wasting of the zinc, and it could, therefore, only be used on small craft.

Copper, tin, and lead have been proposed for coating ships, but these metals are electro-negative to iron, and would rapidly destroy the hull, should any abrasion of the coating or damage to the insulating material take place.

The non-metallic coatings which are intended to do away with corrosion have been almost endless. At the present moment there are upwards of thirty in the market; whilst the patent list of the last fifty years contains an enormous number which were practically still-born.

They may be divided for convenience into—

(*a*) Oil paints.
(*b*) Pitch, asphalt, tar, or waxes.
(*c*) Varnishes, consisting of resins and gums dissolved in volatile solvents.
(*d*) Varnishes, containing substances to give them body.
(*e*) Coatings of cement.

And, before going into these in detail, it is necessary to consider the condition of the surfaces to which they will have to be applied, and the effect this will have upon them.

Air has the power of holding water vapour in suspension, the amount so held being regulated by the temperature; the higher the temperature the more can the air hold as vapour, whilst any cooling of the air saturated at the particular temperature causes a deposition of the surplus moisture. When a ship is scraped down to the bare iron in the dry dock, we have a huge surface of metal which varies in temperature much more rapidly than the surrounding air, and cools much more rapidly than the stone walls of the dock; as it cools so it chills the layer of air in immediate contact with it, and causes a deposition of the surplus moisture on its surface—a phenomenon known as the "sweating of iron"—and on to this moist surface the protective composition has to be painted. If now a rapidly drying varnish is put on, the rapid evaporation of the volatile solvent causes again another sudden fall of temperature—evaporation being always accompanied by loss of heat—and this fall of temperature again causes a deposition of moisture, this time on the surface of the protective, so that the coating is sandwiched between two layers of moisture, both of them probably acting deleteriously upon the resin or gum in the varnish, whilst the moisture on the iron also prevents adherence of the varnish to the metal. If, instead of a quick-drying varnish, the old-fashioned red lead and linseed oil protector had been used, the second deposition would not have taken place, but the sweating of the iron would have prevented cohesion, and, when dry, any rubbing of the coating would bring it off in strips.

The condition of the outer skin of a ship, when she is being coated with her protective composition, is one of the prime factors in the discrepancies found in the way in which compositions act; it being a very usual thing for a composition to give most satisfactory results on several occasions, and then, apparently under exactly similar circumstances, to utterly break down, and to refuse even to keep on. Too much stress cannot be laid upon the condition of the plates at the time of coating, and it is absolutely essential either to have a perfectly dry ship, or else a composition which is not affected by water.

When an old ship is broken up, you will often see on the backs of the plates the numbers which had been painted on them with white lead and linseed oil before the

ship was built, and under the paint the iron in a perfect state of preservation, the secret being that the paint was put on while the plates were hot and dry.

Boiled linseed oil, mixed with red or white lead, is amongst the oldest of the protective compositions in use, but of late years has been but little employed, since it was proved by M. Jouvin of the French Navy, and also in this country, that compounds of lead, when exposed by the wasting of the vehicle to the action of sea water, are converted into chloride of lead, and this is rapidly acted on by the iron, depositing metallic lead and forming chloride of iron, the deposited lead carrying on the corrosion of the iron by rapid galvanic action. The drying of boiled linseed oil is due to the fact that it has in it a certain quantity of an organic compound of lead, and the drying properties are given to it by boiling it with litharge (oxide of lead), so that, even when red or white lead is not mixed with it, still lead compounds are present, and this action will go on to a lesser extent. When the boiled oil dries, it does so byabsorbing oxygen from the air and becomes converted into a sort of resin, the acid properties of which also have a bad effect upon iron, so that protectives containing boiled oil are open to objection. Within the last two months a good example of the action of sea water on the bottom of an iron ship, coated with red lead, has been afforded by H.M.S. *Nile*, which, after being painted over with coats of red lead, was allowed to remain for some months in Milford Haven, with the result that her bottom is very seriously corroded, and, on examination of specimens of rust taken from her, the crystals of metallic lead are in many cases easily identified.

If red lead is used, it can only form a groundwork for an anti-fouling composition which has to protect the red lead as well as the iron of the ship from the action of sea water, and when the anti-fouling composition perishes then serious corrosion must ensue.

The second class of protectives, consisting of tar and tar products, such as pitch, black varnish, and also asphalt and mineral waxes, are amongst the best protectives, the waxes especially not being affected by the sweating of the plates, and forming admirable coatings for the plates. Certain precautions, however, must be taken in the case of tar and tar products, both of which are liable to contain small quantities of acid and of ammonia salts; but if care be taken to eliminate these, and if it could be managed to apply this class of protectives hot to warm plates, the question of protection would be practically solved, bituminous and asphaltic substances forming an enamel on the surface of the iron which is free from the objections to be raised against all other protectives, that is, that being microscopically porous they are pervious to sea water.

The third class of protectives consists of varnishes formed by dissolving gums or resins in volatile solvents, such as spirit, turpentine, naphtha, fusel oil, &c., and such

varnishes are open to several objections. In the first place, they are acted upon by moisture, which causes a deposition of the resins or gums as a non-coherent powder, and destroys the tenacity of the varnish. The amount of action which moisture has on such a spirit-varnish depends to a considerable extent upon the proportion of resin or gum to spirit, when the solvent is present in large quantities, and the resin in comparatively small; then the moisture has apparently little action; but it must be remembered that the drying of such protectives means the rapid evaporation of the solvent and concentration of the resin or gum, whilst the rapid volatilisation which is going on cools the hull of the ship, and causes deposition of moisture on the drying varnish with most disastrous results.

Another point which must be borne in mind is that no such varnish is impervious to gases and liquids. We are apt to think of a coating of varnish as being perfectly homogeneous; but, on examining it through a microscope, it is seen to be full of minute capillary tubes, which become gradually enlarged by the action of water, and finally result in the destruction of the varnish, whilst moisture and dissolved gases find their way to the metal and carry on corrosion. The application of several coats of varnish tends to diminish this evil, as in many cases the holes in the first coat will not correspond with the holes in the second, and so each succeeding coat will tend to make the protective more and more impervious. In using such varnishes, they must only be applied in favourable weather, and must be allowed to thoroughly harden before being brought in contact with the water.

In the fourth class we have varnishes of this kind to which body has been given by the addition of foreign constituents, generally mineral oxides; and this class is far preferable to the last, if the solvent used is not too rapid in its evaporation, and if care has been taken to select substances which do not themselves act injuriously upon iron or upon the gums or resins which are to bind them together, and are also free from any impurities which could do so.

At present the favourite substance used to give colour and body to such varnishes is the red oxide of iron, the colour of which effectually cloaks any rusting which may be going on under it. In using the red oxide for this purpose, care should be taken that it contains no free sulphuric acid or soluble sulphates, as these are common impurities, and are extremely injurious, tending to greatly increase the rate of corrosion. The finest coloured oxides are, as a rule, the worst offenders in this respect, as they are made by heating green vitriol (sulphate of iron), and in most cases the whole of the sulphuric acid is not driven off as the heat necessary impairs the colour; this acid is often neutralised by washing the oxide with dilute soda solution, but very little trouble, as a rule, is taken to wash it free from the resulting sulphate of soda, which is left in the oxide.

A sample of exceptionally good colour intended for using in protective compositions was sent me a few weeks ago for analysis, and proved to contain no less than 15·3 per cent. of sulphate of soda.

The best form of oxide of iron to use for this purpose is obtained by calcining a good specimen of hæmatite iron ore at a high temperature. When prepared in this way it contains no sulphates, but from 8 to 40 per cent. of clay; if the percentage does not, however, exceed 12 to 18 per cent. it is perfectly harmless.

Composition manufacturers can easily test their red oxide for themselves, to see if it contains soluble sulphates, by warming a little of it with pure water, filtering through blotting paper, and adding to the clear solution a few drops of pure hydrochloric acid, and a little solution of chloride of barium (easily obtained at any druggist's). If a white sediment forms in the solution, the sample should be rejected.

In a previous paper on the corrosion and protection of iron and steel ships, I pointed out that when such a varnish perished, the oxide of iron being left in contact with the iron plates, increased the corrosion going on at the surface of the metal, all oxides being electro-negative to the metals from which they are produced, and on that occasion I advocated the use of finely divided metallic zinc, which can be obtained as an impalpable powder, in place of the oxide of iron, pointing out that such a composition would last as long as any varnish of this class, and that, when the varnish perished, as it must do after long exposure to sea water, then the metallic zinc would, on coming in contact with the iron, set up galvanic action; but that, instead of being electro-negative, as in the case of the oxide of iron, and causing corrosion of the plates, it would be electro-positive, and in consequence would protect them, being itself slowly oxidised, and so would give a fresh period of protection.

I hoped at the time that I had made it perfectly clear that the zinc would in no way act until both the anti-fouling and protective varnish had perished, and had become spongy and porous, and that the idea was a prolongation of the period of protection, the great point which has now to be aimed at; but the remarks made afterwards in several journals which were kind enough to notice my paper showed me that they had mistaken my intention, and supposed that the zinc was put in to at once create galvanic action, and predicted that if by any chance it did act, the hydrogen generated would blow the composition into blisters, and defeat its own purpose. I need hardly point out that nothing was farther from my intention, as zinc in fine powder would be acted on more rapidly than the dense metal in plates, and I have already pointed out that this is destroyed too rapidly by galvanic action to render it of practical use as a protective *per se*.

As to the hydrogen blowing off the composition, no gas could be generated until

both the anti-fouling and protective coatings had been perished and rendered perfectly porous by the action of the sea water, a condition which would have permitted the free escape of the generated hydrogen, which, it must be remembered, will permeate through openings which other gases cannot pass through.

One of the largest firms of composition manufacturers had enough curiosity to try the effect of zinc *versus* oxide of iron, and painted a patch of it upon a ship coated with his compositions, and after a long voyage she returned with her protectives in perfectly good order, and had it not been for the patch containing zinc having had its position fixed by careful measurements, its whereabouts could not have been discovered. This is exactly what one would have expected; as long as the varnish remains intact oxide of iron, zinc, or, indeed, any substance which will not damage the varnish, does perfectly well; but had the vessel been allowed to continue until the varnishes had perished, then I venture to say that the patch containing the zinc would have shown better protection than those parts containing the oxide of iron. My ideas have undergone considerable modification during the past two years, but I still consider the views I put forward in my last paper were perfectly sound, and I am every day more and more convinced that the great object the composition maker has to aim at is the prolongation of the life and effectiveness of compositions, and not the multiplication of short-lived devices, however admirable in their action.

In the fifth class of protectives we have cement coatings; but these, together with such schemes as the covering the hull of the vessels with vitreous glazes, glass, &c., have of late years, as far as I know, entirely been abandoned. The action of cement on iron, however, must later on be discussed in its important bearing on the protection of the interior portions of the hull, for which it is largely employed, its weight and the difficulty of attachment rendering it unfitted for outside work.

In selecting a protective composition for the bottom of a vessel, one of the second or fourth class should be chosen, attention being given to the points I have indicated, which are that in the bituminous and asphaltic compositions all the original acids must be eliminated, and that in the varnishes of the fourth group quickly evaporating solvents should be avoided, and, if possible, zinc substituted for oxide of iron.

The vessel should have her plates as dry as possible during the application of the protective, and, if feasible, days on which the air is fairly dry should be chosen. The protective should not be too thick, as, if it is, it does not readily fill into inequalities in the plates; and, if in this way any air is enclosed, change of temperature will cause it to expand or contract, thus causing a blister to form, which will fill with sea water and set up rapid corrosion. The composition must either be elastic or else have the same rate of expansion and contraction as the iron; for, if not, the change of temperature will

cause cracking and tearing of the composition, with disastrous results. The vessel, if she has to be scraped down to the bare metal, must be scrubbed free from all traces of rust, and where a well-adhering coating of composition exists, it should be painted over and not disturbed. In the case of a new ship, she must be pickled with dilute acid, to get rid of every trace of mill scale, and then washed down with some slightly alkaline liquid to neutralise every trace of acidity, the alkali in turn being removed by clean water. Under these conditions, and given a composition with good adhering properties, but little apprehension need be felt as to the ravages of corrosion on the metal of a ship's bottom, the chief risk being from abrasion and other mechanical injury to the composition, coupled with improper constituents in the anti-fouling compositions. The protection of the interior portion of the vessel, where the plates are exposed to the corroding action of bilge water, rendered more active by a high temperature, leakage from cargo, acids and sulphates from wet coals, and the presence of such electro-negative factors as coal dust, scale, and rust, is a matter of quite as great importance as the exterior protection; whilst the great chance of mechanical abrasion during coaling and shifting of cargo, as well as the difficulty of getting at the lower portions of the hold to examine the condition of the plates, renders it a question of the gravest consideration. The corrosion found in the portions underneath the engine-seats, the bunkers, and the water-ballast chambers, especially near the engine-room, is often very serious, and needs most careful watching, which, from the position of these parts of the vessel, it is very hard to bestow upon it.

It must also be remembered that the bilge water in a vessel is in constant motion, and that the air in these parts of the vessel may be expected to be exceptionally rich in carbonic acid gas, which, as I have before shown, is the most important factor in corrosion. Under these conditions any abraded portion would probably be continually washed over, and then exposed to the foul air, a condition of things most conducive to rapid rusting. There are three main classes of protectives for the interior of a ship—

(1) Cements.
(2) Bituminous coatings.
(3) Paints.

The first of these, the cement coatings, have many good points to recommend them, but they also have many serious drawbacks.

The rigidity, firmness of adherence, and endurance are all of them points of the greatest importance, and there is no doubt but that the silicates present in the cement in time not only bind the cement into a mass of wonderful hardness, but also bind the cement to the iron. A point to which I should like to draw your attention, however, is that a thin coating of Portland cement is highly porous, and that it can be permeated by liquids and gases. Suppose, now, that some copper scale from the interior fittings

had fallen into the bottom of the vessel, and had been converted into soluble salts of copper by the saline bilge water, this solution would soak through the capillary orifices in the cement, until it came in contact with the iron below, when the copper would be deposited on the iron, and rapid galvanic action set up, the cement being loosened, and to a certain extent lifted, by the formation of rust, whilst corrosion would gradually extend under the cement, giving on the outside of the coating but little sign of the damage taking place below it.

Also the hardness and rigidity of the cement gives it a tendency to crack away from the metal when any strain is thrown on the plates, or during any expansion or contraction of the metal ; whilst any repairs on the outside of the ship, such as making a boring to test the thickness of plate, replacement of rivets, &c., would undoubtedly cause a loosening of the cement coating within, and, wherever a loosening takes place, the space between the cement and the plate will quickly be found to become a starting-point for corrosion, which quickly spreads and loosens the cement, and will only be discovered by chance.

It is for this reason that I consider bituminous or asphaltic varnishes, freed from any trace of acid, and applied hot, or sound tough paint, preferable to cement ; as, although they are not so hard, yet if serious corrosion should be set up, it is easily discovered and stopped before much damage results, whilst, being impervious to moisture, deleterious solutions, either from the coal bunkers or cargo, would be prevented from acting upon the skin of the ship.

In approaching the subject of fouling, one is impressed with the apparent hopelessness of obtaining any reliable information from the successes or failures registered by the bottoms of the vessels in the Service, or in the Mercantile Marine. Hundreds of ships may be examined, and their condition and the nature of the compositions used upon them registered, and just as one begins to feel that the key to the mystery is within one's grasp, a whole series of results so abnormal suddenly comes to light that it seems impossible to reconcile them with one's previous experience. A ship may sail half a dozen times to the same waters, coated with the same composition—on four occasions she will come home clean, and in good condition, whilst on the other two voyages she may accumulate an amount of weed and animal life sufficient to knock down her speed from nine knots to five. Moreover, if the compositions with which she was coated be examined, and scrapings taken from her on her return, no cause will present itself that can in any way explain the great difference in her condition. After several years' close observation, however, certain factors begin to make themselves apparent. Ships at sea from March to August show a worse average than those afloat from August to March ; one also begins to realise that the amount of fouling increases enormously if the ship has been long at anchor—ships which have been lying at the

mouths of rivers, although quite clean in the brackish water, foul much more rapidly on going to sea than vessels which have been cruising, or even at anchor for the same time, in salt water; and, finally, certain ports and certain seas seem to exercise a deleterious effect, both as regards corrosion and fouling, which is not to be found elsewhere.

Turning back to the naval history of the past, we find that fouling is no new trouble born with the advent of our present iron monsters; but that it has been the one trouble that the combined engineering and scientific skill of many centuries has been unable to overcome.

With our wooden ships, metallic copper sheathing, if it were of the best kind, answered the purpose fairly well; but then the copper wasted so fast that inferior kinds and alloys were substituted to prevent the rapid loss, and, with the slowing down of the destruction of the copper, at once the trouble of fouling returned.

When iron ships began to replace the wooden ones, as was only natural, attempts were made to utilise the metal which had before given relief; but it was quickly found that the effect of the galvanic action set up by the copper was fatal to the iron plates of the ship, and attempts were then made to sheathe the ship with copper plates in such a way that they should be insulated from the iron of the vessel—a condition almost impossible to attain, and attended with great risk should any accidental injury to the insulation take place. Early in the history of iron shipbuilding the idea was started of using coatings of paint, so prepared as to fulfil the same functions as the copper plates had done; but from 1840, when the first paint of this kind was patented, down to the present day, when there are upwards of thirty-two different compositions in the market, very little progress has been made in their manufacture, and the best of the present compounds cannot be relied upon for keeping a ship's bottom even fairly free from fouling for periods extending beyond nine months, and I am personally convinced that the reason of this is to be found in the fact that a start was originally made in a wrong direction.

The idea which originally led to the present class of anti-fouling compositions was that the copper salts formed by the action of the sea water on the metallic sheathing owed a considerable portion of their value as anti-foulers to the poisonous action they exerted upon marine animal and vegetable growths; but, when an observer comes to study the natural history of these lower forms of animal life and vegetation, it is gradually forced upon one that it is only in the early stages of their growth—the germ period—that metallic poisons can affect them. Seaweeds do not take in the constituents they require for their growth by means of their roots, as is, to a certain extent, the case with ordinary plants, but absorb them by means of their pores from the

water itself, the root only serving to attach them to the solid they choose for their resting-place; and it is also well known that when once a marine plant which has passed the first stages of existence is dislodged or torn from its support, it cannot reattach itself to anything else, whilst most of the mineral poisons have little or no effect upon their life and growth.

In the same way we find that, with the animal life found on a ship's bottom, the under side is used to cling on with only, and not as an extractor of nourishment, and that, therefore, after the seeds and germs have once obtained a foothold on the side of the vessel, no amount of poison which can be put into a composition will have any effect upon them. Metallic poisons undoubtedly do exert an influence upon the germs in their earliest stages; but after that they are perfectly useless as anti-foulers, and only imperil the plates of the vessel.

The germs of both kinds of growth are of necessity more abundant in the surface water near shore than in deep water, and therefore the period when the ship is in port is the time when the germs are most likely to make good their attachment, after which their further development is, unless other methods of getting rid of them are employed, merely a matter of time.

On examining the conditions under which a vessel is placed when coated with a composition which relies for its anti-fouling powers on metallic poisons only, we at once see the reasons which must make such a coating of little or no avail. In the composition we have drastic mineral poisons, probably salts of copper, mercury, or arsenic, which have been worked into a paint by admixture with varnishes of varying composition, and each particle of poison is protected from the action of the sea water by being entirely coated by this vehicle; that this must be so is evident, or the composition would not have sufficient cohesive power to stick on the ship. As a rule, care is taken to select fairly good varnishes, which will resist the action of sea water for, perhaps, two or three months, before they get sufficiently disintegrated to allow the sea water to dissolve any of the poison; whilst, even with the accidental or intentional use of inferior varnishes, three or four weeks will pass before any solution can take place, and any poison be liberated to attack the germs. A ship is dry docked, cleaned, and, her anti-fouling composition having been put on, she goes probably into the basin to take in cargo. Here she is at rest, and, with no skin friction or other disturbing causes to prevent it, a slimy deposit of dirt from the water takes place, and this, as a rule, is rich in the ova and germs of all kinds of growth, whilst the poisons in her coating are locked up in their restraining varnish, and are rendered inactive at the only period during which they could be of any use. After a more or less protracted period, the ship puts to sea, and, the perishing of the varnish being aided by the friction of the water, the poisonous salts begin to dissolve or wash out of the composition; but the germs

have already got a foothold, and with a vessel sweeping at a rate of, say 10 to 12 knots through the water, the amount of poison which can come in contact with their breathing and absorbing organs is evidently so infinitesimally minute that it would be impossible to imagine it having any effect whatever upon their growth. If the poison is soluble, it is at once washed away as it dissolves; if it is insoluble, then it is also washed away, but there is just a chance that a grain or two may become entangled in the organs of some of the forms of life, and cause them discomfort. As the surface varnish perishes, the impact of the water during the rapid passage of the vessel through the water quickly dissolves out or washes out the poisonous salts, and leaves a perished and porous, but still cohesive, coating of resinous matter, which forms an admirable lodgment for anything which can cling to it; and by the time the vessel lays-to in foreign waters, teeming with every kind of life, the poison which would now again have been of some use is probably all washed away, and a fresh crop of germs are acquired, to be developed on the homeward voyage, and a "bad ship" is reported by the person who looks after her docking. It is evident that a poison, even if it had the power of killing animal and vegetable life in all stages, could only act with the vessel at rest, unless it were of so actively corrosive a nature as to burn off the roots and attachments of the life rooted to it, and if it did this, what, may I ask, would become of the protective composition and the plates of the vessel? And I think it is also evident that any poison so used must be under conditions in which it is very unlikely to be in a position to act when it might do good.

The lamentable failure of composition after composition of this kind has gradually reduced them in number to some ten or twelve at the present time, and in most cases it is low price alone which keeps them in the market.

The practical proof, given by experience, that poisons alone are unable to secure a clean bottom soon led many inquirers to the conviction that it was the exfoliation in the case of copper which had acted in giving fairly good results, and in many compositions the attempt has been made to provide a coating which shall slowly wash off, and, by losing its original surface, shall at the same time clear away germs and partly developed growths, and so expose a continually renewed surface, in this way keeping the bottom of the vessel free from life. There is no doubt that when this is successfully done, a most valuable composition will result, but the practical difficulties which beset this class of anti-foulers must not be overlooked. In order to secure success, the composition must waste at a fairly uniform rate, when the ship is at rest, and also when she is rushing through the water; and this is the more important in the case of service vessels, as in many cases they spend a large percentage of their existence at anchor, or in the basins of our big dockyards. If a composition is made to waste so rapidly that it will keep a vessel clean for months in a basin, then you have a good

composition *for that purpose;* but send the vessel to sea, and under conditions where you have a higher temperature, and the enormous friction caused by her passage through the water exerting its influence upon the composition, and you will find that the coating, which did its work well for six months at rest in the basin, will, in the course of one month under these altered conditions, be all washed away, and fouling will be set up. Noting this result, the manufacturer renders his composition more insoluble—less wasting—and so obtains a coating which, when the vessel is in motion, scales just fast enough to prevent fouling, and good results at once follow; the composition is then put on the same or other vessels, and they take a spell of rest in the basin, and bereft of the aid of the higher temperatures, and the friction of the water, the composition ceases to waste fast enough, and bad results at once have to be recorded.

There is no doubt that this is the true explanation of the wide discrepancies which are found between the compositions in the Navy and in the Mercantile Marine. Take any of the big lines, their steamers are running at a fairly uniform rate of speed, and the periods of inaction are as short as the desire not to waste the charge on the capital they represent can make them, and under these conditions, by varying the constituents in the varnishes used for anti-fouling purposes, it is fairly easy, given the necessary data, to so constitute a composition as to secure admirable results; but when you come to apply this same coating to an ironclad, running at various speeds, and as often at rest as in motion, then you at once find that the composition you before imagined to be all that could be desired fails just as lamentably as the tribe of anti-foulers which preceded it. It is not so very long ago that I had the honour to serve on an Admiralty Committee under the able guidance of Admiral Colomb, and after inspecting many vessels in the Mercantile Marine, and watching all the dockings of service vessels over a considerable space of time, we were forced to the conviction that it was only in very rare cases that the condition of the bottoms of Her Majesty's ships at all approached the freedom from fouling to be found in the ships belonging to the big companies, with the result that some of the most successful of the compositions in the Mercantile Marine were brought into use in the Navy, and I believe the reports of the dockings since they have been adopted will amply prove the existences of the difficulties I have mentioned.

Another factor which is often overlooked, and which tends to give misleading results, is the action of brackish water, which, in many cases, seems to exert a special action in keeping the bottom of a vessel clean, the fresh water having a tendency to disagree with certain forms of marine growth, whilst the salt water is apparently equally unpalatable to the fresh-water forms of fouling.

In most of the compositions now in use attempts are made to combine strongly poisonous substances with exfoliating and wasting coatings, and this is done by either using metallic soaps, the basis of which is, as a rule, copper, or else by charging a

perishable and easily washed off varnish with poisonous salts, consisting as usual of compounds of either copper, mercury, or arsenic, and in some cases all three.

As I have before pointed out, I do not think the presence of these substances exerts any deterrent action upon the fouling, save perhaps when the vessel is at rest; but they exert undoubtedly an important influence upon the rate of exfoliation, as when the perishing of the varnish exposes them they dissolve, or are washed out, and in this way tend to disintegrate and clear away the surface more rapidly, an important and decidedly useful function, but one which might be more cheaply performed by substances other than high-priced metallic poisons.

The use of metallic poisons of the character indicated throws an increased burden upon the protective composition, as, should the latter become abraded by friction of chain cables, barges alongside, or any other cause, the iron of the vessel will be attacked by the metallic salts, either present in the soluble form in the anti-fouling composition, or rendered so by the solvent action of the saline constituents of the sea water, the action of the metallic salts being to rapidly dissolve portions of the iron, and to deposit the metal which they contain upon the surface of the plates, and these deposits, exciting energetic galvanic action, cause corrosion and pitting to go on with alarming rapidity. Both mercury and copper salts are offenders in this way, but copper is by far the most objectionable, from the fact that the salts formed by the action of the sea water upon the compounds used in the compositions are far more soluble than the corresponding salts of mercury, and are, therefore, liable to be present in much larger quantity, and so exert comparatively a much more injurious action on the plates.

As an illustration of this, two equal portions of sea water were saturated, the one with copper chloride, the other with mercuric chloride, and into each a piece of steel, planed upon one side, and of about equal weight and size, was placed, and left for four days. At the end of this period the two plates were removed, and after being cleaned and dried were again weighed, when it was found that the one exposed to the copper saturated sea water had lost 22·2 per cent. in weight, while the plate exposed to the mercurial solution had only lost 3·6 per cent., this being due to the much larger amount of the copper salt soluble in the sea water.

On now placing these plates in clean sea water, corrosion went on in each case with extreme rapidity, and after being exposed for a month they had both wasted to about the same extent; that is to say, when once deposited on the iron, mercury is practically as injurious as copper.

I am quite aware that this experiment is not at all likely to be carried out in practice, and none can have a greater conviction of the inutility of small laboratory experiments than I have, as they lack all the factors of mass of material and

atmospheric influence which play so important a part in a question like the present; but such an experiment gives one a definite and fairly correct idea of the relative rate of action of the two poisons upon the plates.

All the time the ship is in motion, the wash of the sea water will prevent the metallic poisons doing the plates or the marine growths much harm, but there is one phase of this question which I think has been overlooked. I need not point out that in certain ports there is a fashion in compositions, and that most of the homes of the Mercantile Marine have some pet local composition which is largely used at the particular port. If, now, many ships are lying in a basin, taking in and discharging cargo, and if the prevalent compositions contain copper, it is evident that a certain quantity will go into solution in the water, which often does not undergo frequent or rapid change, and under these conditions every ship in the basin will be exposed to the same danger, and wherever an abrasion has taken place in the protectives, there copper will be deposited on the iron, causing corrosion and destruction of the plates; and it must be remembered that when the vessel is next docked and coated no amount of scraping will remove the fine particles of copper deposited in the pitted and corroded portions of the plate, and so finely divided as to be invisible to the eye, but that they will remain and carry on their destructive work under the new coatings of protective.

It is, I think, a well-recognised fact that, when a vessel coated with a copper compound has become corroded from failure of her protective, or from abrasion, even an entire change of composition does little or no good in stemming the tide of corrosion, until after some considerable period has elapsed, a result which is due to the same cause; and, inasmuch as copper compositions are a source of danger, not only to the ships coated with them, but to any others which may be at rest in the same basin, I do strongly urge upon the manufacturers to abandon the use of these deleterious compounds, and to use others equally efficacious and free from the grave objections I have enumerated.

At the present time, 15 out of the 32 principal compositions rely upon copper in some form or other as the basis of their anti-fouling composition, and in one which has enjoyed considerable favour finely divided metallic copper itself is used, and should a vessel coated with it, after the varnishes had commenced to disintegrate, be moored alongside an iron ship by a chain cable, or even by a wet hawser, a big galvanic couple would be formed at the expense of serious damage to any exposed iron.

In the history of anti-fouling many attempts have been made to obtain highly glazed and glass-like surfaces which it was hoped would withstand the action of sea water, and afford no lodgment to marine growths; but even glass itself is slowly acted upon by sea water, and, when once roughened on the surface, will foul, whilst the

rigidity of such coatings, and the straining and cracking consequent on unequal expansion and contraction of the plates and their coating, offers a serious obstacle to any such scheme.

In concluding this long paper, I wish to point out that in the present phase of the anti-fouling question, and until some new principle for preventing marine growth has been advanced and successfully adopted, satisfactory results can only be insured by an intelligent use of the existing compositions.

The protective composition is the important composition, and care must be taken to obtain the best in the market, as, if the protection is good, the plates remain uninjured even if fouling take place. The anti-fouling composition to be used with it must either be elastic, or have the same rate of contraction and expansion as the protective, and must—at any rate in the Navy—be chosen to suit the work to be done, such as contain copper compounds being carefully rejected, whilst preference should be given to those which rely on exfoliation rather than mineral poisons. If a vessel is to remain at rest for a considerable period, an anti-fouling composition which exfoliates rapidly, and which also contains poisons known to act on germ life, must be used, the amount of such poison depending on the seasons and the waters in which the ship is to be ; whilst if a vessel is to be continually running, then a slowly exfoliating composition must be employed, and a very small percentage of poison is all that is required, as skin friction and the comparative absence of the germs and spores in deep water will do the rest.

Our ships represent an enormous capital, and any trouble or care which will prolong their existence is well worth taking and will be amply repaid, and at the present time a heavily corroded and foul vessel means either ignorance or negligence on the part of those who have the responsibility of deciding on the compositions to be used, and, finally, it must be clearly borne in mind that there is no anti-fouling composition which ever has been made, or probably ever will be made, that will answer for all cases, and that until this is clearly recognised, the present unsatisfactory condition of the question will exist.

DISCUSSION.

Mr. C. F. Henwood (Visitor) : The subject treated in this paper, as your Lordship has very truly remarked, is one of very great importance ; but I cannot speak very favourably of the paper itself, and I must beg leave to say that what is new in it is not true, and what is true in it is not new. There is nothing very new in it, but there are many statements in it which I think I shall show to this meeting are, I may say, fallacious. And I should like the Professor, when he replies, to tell us who he means by " *We* have made but scanty progress during the last twenty years," because I observe later on in the paper his experience of this matter seems not to have extended beyond the

last few years, and in the course of these few years he says, on page 370, "My ideas have undergone considerable modification during the past two years," and I cannot help thinking that in the subsequent two years his ideas will undergo still further modification. On the very first page of the paper the statement is made, and very confidently made, that "corrosion always precedes fouling." Now, that, as an absolute statement, is not true, because what corrosion, I ask, takes place on wood? Wood we know fouls, and a glass bottle fouls, but what corrosion takes place in those cases before fouling occurs? I know of none, and have never heard of any.

The PRESIDENT: But does not the paper refer to iron ships, and not to wooden ships?

Mr. C. F. HENWOOD: The paper states, "Corrosion always precedes fouling," as an absolute fact. The paper refers to wooden ships as well in some parts. Then, more particularly, I wish to refer to that part of the paper which speaks of two methods of protection, one by metallic and one by non-metallic coatings. I do not think the Professor has done justice to this matter, because there are several fallacies in connection with the statements he has made. In speaking of zinc sheathing, he says truly enough that zinc is practically the only metal that can be used for this purpose. Then he says that one of the drawbacks of zinc sheathing was found when it was used to coat wooden ships, that "the metal itself undergoes some physical change, and rapidly becomes brittle." Now, I have taken the trouble—it may be of interest here—to bring up a sheet of zinc, which was supplied to me by Sir Edward Reed, taken from the *Almirante Cochrane*, after having been twelve years at sea, and it is as ductile, I may say, as it was the day when it was put on. Any gentleman may examine this sheet of zinc, which I here produce, and which has been on this ship for upwards of twelve years. I have sent it backwards and forwards in exhibiting it on several occasions, and it has not broken, so that practically the metal, after twelve years' service, remains as ductile as it was the day it was put on.

Mr. B. MARTELL: Was that taken from a wooden or from an iron ship?

Mr. C. F. HENWOOD: From an ironclad sheathed with wooden plank (the *Almirante Cochrane*), so that practically it may be considered the same as if it had been on a wooden ship. There is one other point I should like to notice. Professor Lewes says: "Where the galvanic contact has been but small, there the sheathing has had a short life, but has afforded but little protection to the iron, which has gradually decayed away in a very uneven fashion; whilst in those cases where galvanic contact has been successfully made, the ship has generally returned from her voyage minus the sheathing."* My first experience in this matter—the coating of iron ships—dates from forty years ago, at Malta Dockyard; and ever since that time all the paints and pigments, and the various methods of sheathing, have come practically before me, and I must say that nothing of this kind has ever come to my knowledge. I never knew or heard of a case which would justify such statements. I never knew or heard of a ship where galvanic contact had been made between the zinc sheathing and the iron of the ship, and I should like the Professor to tell us when that occurred, because I never heard of any such case ever having happened. By galvanic contact I do not mean the two metals merely placed together where only their respective oxides may be in contact; that I take it is not galvanic contact, and I believe the Professor will agree with me in that. Therefore, a wrong impression is spread abroad by such statements, coming from such an authority, that "in those cases where galvanic contact has been successfully made, the ship has generally returned from her voyage minus the

* For a correct account of what Professor Lewes actually stated see page 365.—ED.

sheathing." I never knew or heard of such a case; the Professor has not given us a case, and I challenge any shipbuilder or engineer in this room to cite a case in which that has occurred. It never has occurred. Then I am glad to hear that the Professor qualifies the statement that, "so far all attempts at metallic coatings have proved failures." With regard to the two ironclad ships sheathed with zinc by Sir Edward Reed, the *Blanco Encalada* and the *Almirante Cochrane*, there was no metallic contact between the zinc sheathing and the iron itself. The vessels were first sheathed with wooden planks, and made, as Sir Edward tells me, as nearly water-tight as may be, and then the zinc sheathing was simply nailed to these wood planks, but the bolt-head fastenings of the wood planks to the iron hull were left exposed, so that some slight local galvanic action might possibly have ensued. But this sheet of zinc I have here does not show it, although the bolt-heads which were spaced two feet apart, were exposed to parts of this sheet somewhere, yet I am informed by Sir Edward that in certain parts of the ship where these bolt-heads came close to the zinc sheathing, the oxidation of the zinc was slightly greater. These two ironclads have shown us I think something which it is very important to know, and that is, that zinc sheathing is a lasting material in sea-water; in fact, as applied in these cases, too lasting, because to keep clean in the same way that copper does the zinc sheathing must waste away at the same rate in order to prevent these barnacles and vegetation permanently adhering to the sheathing. In order to make zinc perfectly answer the purpose and equal copper, it must be brought into galvanic contact with the iron or steel, and I think I am justified in saying from the experience gained from these two ironclad ships, that if the zinc sheathing was placed directly on the iron or steel, and brought into galvanic contact, the necessary amount of oxidation of the zinc sheathing would be obtained which obtains with copper sheathing under ordinary circumstances on a wooden vessel.

The President: It is my duty to remind you that you have exceeded the ten minutes' limit which is prescribed by the rules of the Society.

Mr. C. F. Henwood: I have only a few more observations. Of course, my Lord, there is much to discuss in this paper, and it is impossible to discuss all the points within ten minutes.

The President: That is the rule of the Society, as I am bound to remind you. It was only because of a special occasion that that rule was departed from on Wednesday. It was agreed by the Council that that was a special occasion, but to-day I must remind you of that rule.

Mr. C. F. Henwood: With regard to the statement that the waste of the zinc sheathing would be so rapid that it would practically have to be renewed every voyage, the Professor gives us no data. It is merely his idea. All my experiments and all my practical experience of the matter show that zinc sheathing applied in this way (directly and in galvanic contact) would last five or six years. I can only add that I have a specimen here for examination by any practical shipbuilder or engineer, and I shall be happy to give any further explanation with regard to it.

Mr. J. I. Thornycroft (Vice-President): I would like to say one or two words on the paper. What I have to say will be very brief. The paper states that galvanising has been attempted in ships or boats, and that it is perfectly useless. Well, this is all news to me, I may say. My firm has been accustomed to build boats, and to galvanise the whole of the plating before they are put together. I think to galvanise a boat of any size after it had been riveted would be futile. Thirteen years ago we built a number of boats, I think some of the first were for the French authorities, and these were all galvanised, and these boats are still at work, and we have heard nothing of

any trouble from oxidisation. It may be that the zinc is not so useful as we think it is, but it certainly seems to lead to much greater durability. The plates in these boats are exceedingly thin, and the boats, I believe, are still in excellent order. I do not know that I have any more information to lay before the meeting.

Rear-Admiral P. H. Colomb (Associate): I am sorry to say, my Lord, that though, two or three years ago, I might have been able to contribute something useful to the discussion, to-day I only rise when called upon to express my admiration for the ability displayed in the lecture, and the extreme lucidity with which the arguments have been put forward. My own experience, when I was hot on the subject and working at it, coincides mainly with the views that the lecturer has now put forward. I know my views must have been somewhat influenced by the powerful intellect which I had to deal with in my colleague, the lecturer, but there are just one or two practical points—without going into the immediate question of the chemical action, and the natural history part of the subject—to which I should like to call attention. In the Mercantile Marine at present the Board of Trade regulations for docking make the question of anti-fouling of less importance perhaps, because, as far as I understand, the addition of the recoating to the cost of docking is a comparatively small one; and, therefore, although all the parts of the paper relating to the anti-corrosion coverings apply with great force to the Mercantile Marine, so far as I understand at present, the frequency of docking prevents the anti-fouling part of the question from presenting the great importance to our view that that part of the question displays when we come to think of the war-ships. In the case of battle-ships and what they will have to do in war, I look upon the maintenance of these ships at sea, and the continuance of their speed, as of very great importance. But the duties of the battle-ships in war, so far as we know, will largely consist in lying comparatively idle in still water watching. That was the state, you may remember of the blockading squadrons in the Naval manœuvres last year. Of course, if that remaining still in water was continued for any time, the growth on the ships' bottoms, whether vegetable or animal, would very soon accrue to such an extent as to vitiate that great speed which we now demand. Those extra half knots, which cost us so much in weight and money, would be made to disappear by a very small amount of fouling of the ship's bottom; and, therefore, I think the lecturer is right in dwelling strongly on the subject of the anti-fouling, even though it does not apply so closely to the Mercantile Marine, and I would wish to corroborate him also in his historical statement as to the trouble that this very question of fouling was to our forefathers. It was a greater question 200 years ago, a much greater question, than it is now. I have only one observation to make in conclusion, but I am not sure whether I have mentioned to the lecturer the view I hold upon the subject, whether it might not be possible to get over the fouling, not by introducing the poisons into the composition, but by introducing the germ-killing poisons into the water which surrounds the ship. It would seem to me sometimes that if you were able to go at very slow speed, and to introduce somewhere at the cut-water—somewhere near the bow of the ship—at three or four different levels, poisonous mixtures poured from the deck into tubes opening to the water at these levels, you might succeed in placing the ship in a condition of poisonous water for the time necessary to destroy the germs. The lecturer alluded to the destruction of life which takes place when the character of the water in which the ship floats is changed, and it is common for us—it is common for some of us at any rate—with ships that foul rapidly, to pass when we can into fresh water up a river for the purpose of killing the growth upon the bottom; and the question I would like the lecturer to consider is, whether it might not be possible by some arrangement, by carrying certain chemicals on board the ship from time to time, to poison the water surrounding the ship so as to destroy the animal and vegetable growth?

Mr. John Corry (Associate Member of Council)): The subject of the lecture is one of very great importance to shipowners, and I have taken some interest in it. Without pretending to the special knowledge of the lecturer, the first point that struck me when Mr. Lewes was reading his paper was the statement that corrosion always preceded fouling. That would, apparently, render anti-fouling simply dependent upon the protection of the vessel from corrosion. I think it must be the experience of all who are accustomed to inspect ships in dry dock that fouling did occur where there was not a particle of corrosion, at least such corrosion as they could examine by the naked eye. Whether or not there might be some slight corrosion of an infinitesimal kind going on that we could not see, I cannot pretend to say, but certainly our experience has been that there has been a vast amount of fouling without at least any apparent corrosion. Whether this statement is meant literally or not I do not know, but it seems to me to require some explanation.

Professor V. B. Lewes: I think I might save time, sir, if I explained that that sentence was not at all meant in the light you took it. What I meant was, that if you had a sheet of bright iron and put it into salt water, without any protection in the shape of anti-fouling composition, that under those circumstances corrosion would precede fouling. That is not to be taken as being an important point in the prevention of fouling; it is merely to be taken as giving historical precedence to corrosion over fouling.

Mr. John Corry: I quite understand your explanation. As it appeared here it was to my mind rather misleading, and your explanation will be, no doubt, useful. There was another point referred to, to which as a practical shipowner I somewhat demur: that is, as to condemning the use of red lead as a protective painting both for inside and out. My experience certainly has been very much in favour of red lead. We generally mix it with a certain proportion of white zinc, and certainly for interior coating, and where it is used as a first application to iron, I believe that experience proves it is quite as good as any other compound that has been tried; at least we have found it so. I think that the lecturer has very clearly indicated where the weakness and failures have arisen in attempting to poison these little animalculæ in a way which is practically of little use. Exfoliation is, no doubt, the proper principle to go on, but the difficulties of carrying this out under varying conditions have been very clearly put before us. No doubt great practical benefit will be derived from the study of this paper.

Mr. E. Blackmore (Associate): My Lord, I should like to give an experience of my own, which, perhaps, may be serviceable to the meeting, and have some bearing on the remarks which the lecturer has made on the application of zinc paint primarily to ships. I was engaged for some few years prior to 1857 in supervising the building of iron ships, and in almost all those vessels I found that the practice was to coat the vessels with red lead. I had occasion to build a ship with an eminent firm at Greenock in the beginning of 1857, and as the work proceeded, unfortunately, as I thought at that time for me, there was a delay owing to stress of business in the delivery of some plates; and I began to be very much alarmed at what I thought to be the rusty state of the bottom of the vessel, in consequence of their not coating the plates as they were put on, which I believe is too often erroneously done in the present day. The plates were very fairly rusted before any paint was put upon the bottom of the ship at all. If the work had gone on fairly she would have been painted in her first coat somewhere about the month of April, but as it happened it was the very height of summer before the plates were sufficiently on to allow of the first coat being put on. When the first coat was put on, to my surprise (the good old-fashioned red-lead paint was not used) I found

a grey paint being applied as the first coating of the vessel. I demurred to this, because I, like everyone else, thought that red lead was the only proper application to an iron plate in the first instance. I made inquiries about this, and they said it was a paint that they were experimenting with at that moment, and which they thought would become a very valuable paint indeed. I did not care about having experiments tried upon my ship, but, however, the painting went on, and I inquired afterwards what kind of paint it was. It was of a grey colour, and I was told it was a first-class *zinc paint*, with no lead in it at all, so far as I understood. She was afterwards coated with Peacock's paint. In November I took the vessel out to India, and I had no opportunity of putting her into dock, as she was actively employed in Government service as a transport, until the November following, at Calcutta. All that time she had been employed at Rangoon, the Straits, and elsewhere, which are very bad fouling stations. When I docked in Calcutta the vessel was not nearly so foul as I anticipated. The original Peacock's paint was very nearly all washed off, but to my great surprise the whole of the bottom of the ship still retained in its entirety the coat of zinc paint which had been put upon her. I was in the ship for four years afterwards, and docked her very frequently. On one occasion when we were employed in the transport service in the North of China—and were a long while up there—when we got back to Wampoa we found a large quantity of oysters on the ship's bottom. Seeing the ship was so exceedingly foul, I was anxious about the state of her bottom. To my great delight and surprise I found that the whole of the oysters—they were pure oysters, and nothing else—came off with the coating of white zinc paint and red lead, which I had been accustomed to apply to the ship as an outer coating, after being well mixed up in a small Indian rice mill with 20 lbs. of arsenic. This outer coating did not prevent fouling or the growth of the oysters, but after being well scraped, I found that the ship's bottom still retained the coating of zinc paint, as pure as the day it went on, and the only part of the ship's bottom in which I saw rust in the whole four years was at one of the keel rivets, which I think may bear out what has been said by the lecturer with regard to zinc paint.

Mr. J. H. Heck (Member): My Lord, I must congratulate Professor Lewes upon the very interesting paper which he has brought under our notice, and for the very valuable information it contains. There are, however, a few things in it which seem a little opposed to general experience. As Mr. Martell can take these points up much better than I can do, I propose only to deal with one, and that is the question of corrosion within double bottoms. I, at one time, shared Professor Lewes's views on this question, but the internal examination of a number of tanks or double bottoms has convinced me that practically, inside such spaces, there is very little corrosion. I have examined a good many double bottoms in vessels of various ages, and I believe if Professor Lewes did the same he would satisfy himself that some little modification is necessary in the statement made on page 371, viz., "the corrosion found in the portions underneath the engine space, the bunkers, and the water ballast chambers, especially near the engine-room, is often very serious." So far as I have seen, generally, there seems very little corrosion within the water chambers or in way of the bottom of the engine-room, the grease which finds its way into the bilges of the engine-room apparently preventing any serious corrosion in this space. In conclusion, I have only to thank Professor Lewes for his very valuable paper.

Mr. B. Martell (Vice-President): My Lord, I feel that we are very greatly indebted to Mr. Lewes for bringing forward his paper before this Institution, and more particularly considering the opportune character of it. It comes at the very right time. We are now going from the building of iron ships to the building of steel ships, which is a very much purer material than iron, and we have

now gained sufficient experience to know that the purer the material is, the more it is liable to corrosion, particularly from the action of salt water. In former times, in some instances, we have had iron ships riveted with Low Moor or Farnley iron rivets, and that is a very soft, pure material, very similar to the mild steel of the present day. Our experience was that when the paint was rubbed off the bottom, or worn off, and the salt water came in contact with these rivets, more rapid deterioration took place at the riveted points than with the hard and comparatively impure iron. That being so, we naturally expected that in ships built of mild steel—a perfectly pure material—unless they were properly protected, and carefully looked after, more rapid corrosion would take place, and that has been our experience up to the present time ; and to such an extent has this now gone, that some owners of steel ships are, in my opinion, unnecessarily alarmed with regard to the durability of these ships. Very recently we had one of those ships classed in Lloyd's Register placed in dry dock at the Antipodes, and our surveyor out there reports that she was corroded to a very considerable extent all over her outside surface. And on this report coming before us, we thought that it would be very beneficial if we gave shipowners generally the benefit of our experience in the matter. The consequence was, that the Committee of Lloyd's Register had a circular prepared drawing attention to the experience that we had gained with regard to the deterioration of mild steel, and likewise to the means of preventing this deterioration, viz., by keeping the surfaces carefully protected by paint or suitable composition. On making inquiries into this case, we found that the ship referred to, after being launched, had been lying in the river a considerable time, and then went to sea, and had never been examined or painted for eleven months. Therefore, no one can wonder at deterioration going on under such circumstances. It would certainly be a matter to be deplored if, after having produced a beautiful material like mild steel, for the building of ships, through the carelessness of a few shipowners, others felt it desirable to go back again to the old, inferior, unsatisfactory iron. In the circular referred to, we show that there can be no doubt that if steel ships are properly looked after, and properly coated in the first place, and more particularly the black oxide scrubbed off, in order to prevent any galvanic action being set up—if then the vessel is afterwards scraped and properly coated at proper intervals with good paint—not with some of the rubbish that they call paint, but with real paint, such as I know can be obtained in this city, no alarm need be felt as to the deterioration of steel vessels, as they will, in my opinion, be quite as durable as the iron ship. I am very glad to have the opportunity of saying this, in order, if possible, to allay the alarm of those who own ships built of mild steel. I am very sorry there is one point on which I have to disagree with my colleague, Mr. Heck. He is a gentleman of very great ability ; we have listened to him here, and have derived great benefit from his lectures ; but I must say my experience does not go with his in the remarks he has made. We have found from our experience—I have, at least, personally—that the paragraph referred to is perfectly correct ; that the corrosion found in the portion underneath the engine space and bunkers near the engine-room is often very serious. It is often very serious there, and so much so, that we make special provision that all the inner bottoms of double bottom ships must be thicker, in order to provide against this increased corrosion. It is, I need not say, the heat which contributes so much to this, and which causes this greater corrosion to go on. With regard to the side bunkers, our recent experience has been that unless they are very carefully protected by good paint or other composition, deterioration goes on so rapidly there that I myself have seen nearly the whole of the frames in the side bunkers of a small steamer eaten away. Since then we have had to draw particular attention with regard to the examination of these parts, which were not sufficiently attended to before, and I should like to say to shipowners who are here, that it is of the greatest importance that they should attend to that part of the ship with the greatest care if they wish for durability in steel ships. I may say with regard

to water ballast chambers, that we have found that in some instances, in taking in water into these water ballast chambers, there is a deposit of slime which comes from the water, which forms on the surface of the plate, and seems to have a protecting effect.

Mr. J. H. Heck: My remarks were intended only to apply to the inside of the double bottom, not to any other part of the vessel.

Mr. B. Martell: I am very glad that explanation has been made, because I did not understand it as such. Now, with regard to the remarks of Mr. Henwood, I should like to say a word, because I think he has been very hard on Mr. Lewes. I should be very sorry to be so hypercritical as he has shown himself to be of an excellent paper like this, which is calculated to do a great amount of good, so much good that I am going to suggest when I go back that we should order, say, five hundred copies; so much value do I attach to it that I intend to recommend that we should purchase those for distribution amongst our surveyors. Mr. Henwood said that he did not know anyone who had seen a galvanic effect produced by the contact of zinc with iron in an iron vessel.

Mr. C. F. Henwood: Any vessel in which galvanic contact had been made between the iron and the zinc; and by galvanic contact I meant, not by the bringing of two oxides in contact, but metal to metal, as you would in a battery.

Mr. B. Martell: There was a case in point. Mr. Henwood had a patent or plan of his own for covering iron vessels with zinc, and one vessel was done under the supervision of one of the surveyors of our Society.

Mr. C. F. Henwood: I think, my Lord, I have explained that to Mr. Martell once, and I hope he will remember the explanation I gave him, and not put that forward now.

Mr. B. Martell: I do not, sir.

The President: You are not in order, Mr. Henwood.

Mr. B. Martell: I only remember the fact, and that was that after a voyage or two nearly the whole of the zinc was gone, and the owner was so dissatisfied that he had the remainder of it taken off, as he had no confidence in it. With regard to that sheet of zinc, eleven years old, which he has brought here to illustrate that zinc is an excellent sheathing for vessels, I can only say that is contrary to my experience. There may be an isolated case of that kind, but it would require great explanation to make me have any confidence in the durability of zinc beyond four or five years, and even very much less than that. To bring a specimen of zinc here, and say that because it has been on a ship's bottom eleven years, therefore you can with confidence use it, and expect it to last this time, does not commend itself to me from my experience at all, because my experience is directly opposite to that, and more particularly where it is likely to come into contact with the heads of yellow metal or copper. However, Mr. Lewes is not talking about the action of zinc on the bottoms of wooden vessels; he is speaking here essentially about steel vessels and iron vessels, and I think, as has been said by Admiral Colomb, that his experience, and the information that he has given us here, is of a very clear and precise nature, though Mr. Henwood, from his professional experience of many years may be enabled to say that to him there is nothing new in it. I am quite sure that the shipowners of this country will find that there is a great deal new to them; and if they had only been in possession of the information that is contained in this paper some few years ago, we should not have to deplore now the loss to them which in some instances has occurred with regard to the corrosion of steel vessels.

Mr. J. R. Fothergill (Member): My Lord and gentlemen, having a considerable number of merchant steamers under my supervision, this paper appears to me to be one of great importance, and I was extremely glad to hear the suggestion of Mr. Martell, that it might be possible to issue copies of this paper to shipowners direct, for it seems to me to convey information that shipowners are certainly not aware of. I should like to draw the attention of Professor Lewes to two points in particular that I do not observe mentioned in the paper. One is in relation to the use of steel or iron for steamers' decks. We have found very great trouble in cargo steamers due to the corrosion of these decks, and, so far as my experience goes, we have not been able to apply anything that will at all prevent the corrosion. The more you chip the plates, the more you offer fresh surfaces to corrosive action, and the quicker the decks disappear. I believe that in many instances both shipowners and shipbuilders have decided to abandon the steel deck, due to the excessive corrosion that takes place. As to the corrosion of the bottom of the steamer, that is, on the outer side of the plates, I have not found, where care has been taken, that we have much trouble. We certainly have had great trouble in the fouling of the bottoms of steamers. I am alluding more particularly to steamers in the Indian trade to such ports as Kurrachee, which is, perhaps, the most notorious of all ports; but ports generally on the coast of Madras are all bad in this respect. The bottom, in a very short time, becomes covered with grass and shells. As to the actual corroding of the material itself, I say that we have no difficulty in getting over that where care and good material is used in painting. Now as to what is technically called the boot-topping, that is, the side of the steamer between light line and load line. Here we find some difficulty; ordinary paints are often used simply because patent paints are not found of much value. For instance, take a steamer at one of the Indian ports. Whilst discharging cargo, the boot-topping rises out of the water, and becomes exposed to a hot sun, which soon destroys the anti-fouling properties of the paint; and on the ship again being loaded, and the boot-topping immersed, it quickly fouls, and thus cheap paints are used. Then, again, during the voyage the steamer lightens, due to consumption, thus exposing the boot-topping, which is again immersed on bunkering, and so at this particular part we have a continual variation of the water-line, which causes the paint to crack and blister and peel off, and so leave the plates bare to corrosion. There is one question which struck me very forcibly, and I think it will have weight with the shipowner, and that is the question of quick-drying paints. The shipowner naturally considers it of great advantage to get a quick-drying paint. It is very essential that a steamer should be quickly painted and got out of dock into a loading berth, and many owners and others in the same position as myself—having the supervision of steamers—not having realised this point, have looked with considerable favour on quick-drying paints; but, after all, we must not lose sight of the commercial question, as to whether the extra time in dry-dock for slow-drying paints is not worth the cost. Then as to cement in the tanks of ships, I cannot say that, so far as my experience goes, we have much difficulty with corrosion, that is, in the water-ballast tanks. It is not active there. The Portland cement frequently used to prevent corrosion on tank tops certainly does not appear to stand very well, and I notice one remark of Professor Lewes relative to copper, &c., permeating the cement. One case that came forcibly to my notice was that of a steamer in the copper ores trade. I actually saw in that case, where the tank tops had been very carefully coated with Portland cement to a very considerable thickness, for the purpose of preventing this action, that when it was chipped off for survey, there was actually a layer of pure copper $\frac{1}{32}$-in. thickness, which must have permeated through the cement, and was in actual contact with the iron, doing, of course, an enormous amount of harm in the way of corrosion. Though there is much I should like to say, my Lord, I think perhaps I shall consult the feeling of the meeting by now concluding. Yet I should like to repeat, if the suggestion of Mr. Martell can be carried

out as to the circulating this paper amongst shipowners, it would be of material benefit, and, I feel sure, thoroughly appreciated.

Professor V. B. Lewes (Associate): My Lord and gentlemen, in the opening paragraph of my paper I pointed out that my object was more to excite discussion than to bring before you any very new or startling discovery, and in this I think you will admit it has been successful. In opening this discussion Mr. Henwood took me very severely to task, and commenced his remarks with an unacknowledged quotation from Dr. Johnson, but, unfortunately, did not copy the great master in brevity as well as wit. I seem to have excited and annoyed Mr. Henwood very much by my remarks on zinc sheathing, but you have heard what Mr. Martell—our greatest living authority on such matters—thinks on this subject, and he has told us not only his own experience, but also Mr. Henwood's, which I think bears out my statement, that given no metallic contact the zinc will last a certain number of years, but will be perfectly useless for protective or anti-fouling purposes, whilst if there is proper galvanic contact the zinc will be destroyed too quickly for it to be of practical use. Mr. Henwood declares that proper galvanic contact has never been established between the iron hull of a ship and the zinc sheathing, and if this is the case I fail to see how he can be so confident as to the life of the zinc if contact were made. With regard to Mr. Thornycroft's remarks, which formed a pleasing contrast to the method of criticism adopted by the first speaker, I may say that my observations were intended only to apply to galvanised iron in direct contact with sea water, without any composition over it, and there is no doubt that when it is itself protected from the solvent action of the saline constituents of sea water, galvanising forms a most perfect protection to the iron. Personally, I have had no experience of the length of life of galvanised iron surfaces, and my remarks are founded on the work done by Robert Mallet, F.R.S., one of the most careful observers in this branch of science that we have had, which will be found in the British Association reports for 1843, and is again referred to in a paper by him, which will be found in the Transactions of this Institution for 1872. Admiral Colomb suggests the use of poisonous liquids injected into the water round the ship in order to destroy germ life in contact with the sides of the vessel, but I am afraid that even with the vessel at rest, unless she were in a basin, the run of the tide or currents in the water would sweep away the poison before it would have time to act on the germs. Mr. Corry called me to task for saying that corrosion preceded fouling, but, as I have already mentioned, I was alluding to exposed metallic surfaces, and not to ships coated with protective compositions. Mr. Henwood also touched on this point, and asked how this would apply to glass bottles, &c.; and he could not have chosen a better example, as all the time a glass surface keeps smooth and bright, fouling does not take place, but as soon as a roughening of the surface occurs, although perhaps only to a microscopic extent, then deposits form on the glass, and fouling ensues. It must be remembered that the roughening of the surface of glass under the influence of sea water is corrosion, although of glass and not of iron. Mr. Corry also spoke of the excellent effect of red lead, and there is no doubt that when a coat of oil and red lead are put on a ship it makes a most excellent varnish, because the red lead enters into combination with the oil to a certain extent; but, as I have pointed out, when blisters form in the protective and the red lead is acted upon by sea water, metallic lead is deposited on the surface of the iron, and serious corrosion must ensue. I have to thank Mr. Blackmore very much indeed for his testimony with regard to zinc paints. I always felt, on theoretical grounds—although I never had, until Mr. Blackmore spoke, any definite evidence on the subject—that finely-divided zinc would be the right thing to put into protective paint. As to the question of cost, I am quite sure any owner of a steam-vessel would not be so mad as to look at pence, when thousands of pounds were hanging in the balance. As to Mr. Heck's remarks,

coming from so great an authority, they are very valuable indeed, and I was delighted to hear his testimony that there is no corrosion practically going on in the bottom of the ship. I quite agree that the grease which finds its way down to these bottoms must be a very good protector indeed; but I am also quite certain, from experience, that very serious corrosion does take place in the positions I have named. With regard to Mr. Martell's observations, all of them were so kind that I have nothing to reply to what he said, except to thank him for bearing me out in several very important points. Mr. Fothergill brought forward several interesting points. There was the corrosion of the steel decks, which is a very difficult question indeed, because you subject your steel decks to such an enormous amount of wear and tear, and you have got all the knocking about of the surface, which must necessarily clear away the various paints and protectives, which are worse than useless when you have only certain portions of the metal covered. Where you have got exposed patches and covered patches of metal, they are really under different conditions, and this all tends to help on corrosion. Another interesting point brought forward was that of the deposition of copper under the cement—a fact which bears out fully what I pointed out in speaking of Portland cement; that is to say, its porosity allows of filtration through of liquids containing substances capable in this way of setting up action. As regards quick-drying paints, I think it is a most important question for you to consider. I think if you must coat a ship, and get her out on a tide, you would probably do a great deal better for the protection of the plates if you put on some coating which had to be liquefied, and which, put on hot, hardened as it grew cold, which would be a more effective way of getting quick drying than by using these excessively volatile solvents. I have only now to thank you, gentlemen, for the kindness with which you have received my paper.

The President: Gentlemen, I venture to think the paper which has been read, and the discussion which has followed upon it, is, in the interest of the great mercantile marine of this country, as important and valuable as any paper which we have heard read for many years in this room, and I wish to be allowed to make one suggestion, and one only, and that will be very short. It is a suggestion that has conveyed itself to my mind from a very long experience on the Council of one of the most important societies in England. I throw out the suggestion for what it is worth, having the interest of the Mercantile Marine most deeply at heart, as you all know. In the Royal Agricultural Society of England we have employed for years an eminent analytical chemist, and all the substances that our agricultural friends employ can be at a very moderate fee submitted to careful analysis, and the result of the analysis is published, and is at the disposal of every man using these different compounds in the shape of manure, feeding stuffs, &c. I want to know why our great ship-owning associations in this country should not take a leaf out of that book, and why they should not have at their disposal an analytical chemist at all times. A moderate fee—a very small fee—only would be required from the members, and a slightly larger fee from outside persons, but there would be a man in whom you would have confidence, and to whom you might submit all specimens of these compounds and these paints, and all these various ingredients which we have been discussing. They would be submitted to careful analytical examination, and you would then have it ascertained for a certainty whether it did or did not contain deleterious elements, or whether it was a preservative compound in itself. I throw out this suggestion for your consideration, and I do think it is worth your while to consider it. I now proceed in the discharge of a most agreeable duty, to return our grateful thanks to our friend here for his valuable paper, and the admirable discussion which has followed on it. I shall use whatever influence I possess on the Council to ensure a large circulation of this very valuable paper.

ON THE PART PLAYED IN PROPULSION BY DIFFERENCES OF FLUID PRESSURE.

By R. E. Froude, Esq., Associate Member of Council.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 12th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

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§ 1. Two very important papers bearing on the theory of propulsion have been read at the two preceding annual meetings of this Institution, the one by Professor Cotterill in 1887, the other by Professor Greenhill last year. I regret to have to confess that I omitted to read Professor Cotterill's paper until immediately before last year's meeting, and at first I was unable to see my way through the problems it suggested. Consequently, in the discussion on the paper by Professor Greenhill, which has an important bearing on the same problems, I felt unable to take any useful part, and the more so since this latter paper was printed only just before it was read. The outcome of my subsequent studies of the subject I have embodied in the present paper, and in that entitled "Remarks on Professor Greenhill's Theory of the Screw Propeller."

§ 2. The propositions contained in Professor Cotterill's paper, so far as material to my present purpose, may be stated thus: (1) A propeller, under ordinary circumstances, tends to create an excess of pressure behind it, relatively to the undisturbed water, but *not* a defect of pressure in front of it, excepting so far as arises in a screw from a suction near the centre due to rotation of the race.* (2) Otherwise than this, defect of pressure in front can only be consequent on an impeding of the access of water to the propeller, as by the stern of a ship with a specially full run. (3) The difference of pressure in front and behind must constitute an addition to the thrust represented by the sternward momentum imparted to the race.

§ 3. I must confess to some surprise that the position here adopted by Professor Cotterill has hitherto excited so little remark, conflicting as it does with the

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* Professor Cotterill (*vide* Trans. I.N.A., 1887, p. 293) suggests a further cause of reduced pressure in front of an ordinary screw propeller, which he regards as incidental to the fewness of the blades. This I do not quite follow.

perhaps vaguely defined but hitherto very generally accepted supposition, that the acceleration of the water to which the thrust is due, necessarily commences some distance in advance of the propeller, thus involving there a region of reduced pressure. Indeed, this notion might almost have been described as a commonplace in the science of propulsion. Yet, challenged for a proof of it, it was not easy to find a satisfactory reply. To appeal to the hitherto accepted treatment of the mechanical operation of propellers was clearly useless, since this strictly takes no account of any acceleration beyond the confines of the propeller, nor recognises any mechanical operation whereby such acceleration can be effected. A propeller is, in fact, treated as an expedient whereby undisturbed water is somehow implicated in a machine, forcibly compelled to assume the speed of the machine, and so discharged; the momentum due to the speed thus forcibly communicated being the measure of the thrust exerted.

§ 4. That this treatment strictly applies only to ideal conditions very far removed from those of ordinary practice we have all been long aware, but the fact that the treatment has so long held the field bears witness to the difficulty of remedying its essential imperfections. At any rate, speaking for myself, it was only when I came to study the subject anew, under the stimulus and with the aid of the papers of Professor Cotterill and Professor Greenhill, that I was able to frame for myself a mechanical conception which should adequately illustrate that precise operation of a propeller which the older treatment specially fails to recognise, viz., its operation upon the water not immediately in contact with it.

§ 5. The difficulty underlying the subject appeared to me to centre in this, that whereas the dynamic operation of propulsion is one which in theory depends solely on forces due to fluid accelerations, this operation seems in ordinary propellers to be inextricably mingled with the theoretically distinct conditions proper to the resistance due to established motion. My search for an ideal propeller, from which the element of established motion should be entirely excluded, and which should operate solely by acceleration, led me to the following conception :—

§ 6. Imagine a thin vertical plate, of finite area, immersed deeply in water, and acted upon by a finite normal force T. This force involves a difference of pressure on the two sides of the plate, which at first will be satisfied purely by acceleration of the neighbouring water. If, indeed, the operation is prolonged, a sensible speed will be attained, and a resistance proper to established motion will arise, which will presently supersede that proper to acceleration. But, instead of this, and as an alternative method of constantly maintaining the force T, suppose that after the plate has operated with that force for only an infinitesimal instant $d\,t$, and, therefore, before it has acquired any finite speed, it is abolished, and its place taken by a similar plate similarly actuated, inserted a distance $= v_1\,d\,t$ in front of it, this one

in turn giving place to another, in similar fashion, and so on. The actual change of speed of each plate will, of course, be infinitesimal, each for the brief moment of its existence being practically stationary in the column of water in which it is inserted. And the succession of plates will in effect constitute a propeller, maintaining a constant thrust = T, and advancing in reference to the column at speed v_1. But although the change of speed undergone by each individual plate will be infinitesimal, the infinite succession of plates, operating successively as they do to a great extent upon the same mass of water, must in a finite time produce a finite increase of speed of the column, and thus the speed of advance of the propeller in reference to the undisturbed water, = V, will become less than = v_1, by an amount, at first increasing, and becoming constant when the force represented by the momentum of the successive additions to the length of the moving column equals the constant force T.

§ 7. Whereas, then, the older treatment of the operations of propulsion is strictly applicable only to the conception of a propeller such that the whole of the acceleration (with its attendant contraction of column) takes place within it, we have now arrived at a conception of a propeller which may be described as the opposite extreme, one, namely, where the whole of the acceleration takes place without the propeller; which last, so far as the water is concerned, may be regarded simply as an advancing surface of instantaneous change of pressure. In both conceptions alike, the thrust reaction consists ultimately in the momentum due to the speed imparted to the column by the propeller; but in the one this is regarded as effected directly, and in the other only mediately by means of the change of pressure.

§ 8. For convenience of reference, I will distinguish acceleration which thus takes place without the propeller from that which, as in the old treatment, takes place within it, as "external" and "internal" acceleration.

§ 9. That this difference of pressure before and behind a propeller in which the whole acceleration is external must, at least in part, consist of a defect of pressure and corresponding acceleration in front of it, follows from the supposition that v_1 is greater than V (and if this supposition were not correct we should be getting thrust without slip). But from the reasoning on which rests the well-known proposition that the theoretical work wasted in slip equals the thrust into half the speed imparted to the column (viz.—

$$= T \times \frac{S}{2}$$

as it is commonly expressed), it in fact follows that of the whole acceleration, exactly one-half must take place before the propeller, in obedience to defect of pressure, and the other half behind it, in obedience to excess of pressure.

In other words—

$$v_1 = V + \frac{S}{2}\ *$$

§ 10. Before proceeding to examine how far ordinary propellers should or may be regarded as approximating in condition to the ideal conception at which we have arrived, it is desirable to approach the same conception by another track, whereby we may incidentally learn something as to the character of the stream lines which the conception presupposes.

Imagine a straight tube (Fig. 1, Plate XXXV.) tapering very gently from a sectional area = A at the large end to $= A \times \frac{V}{V + S}$ at the other, stationary in an infinitely extended stream of water flowing past it, parallel to its axis, at speed V; and that the water is entering the tube at the large end at this speed V, and therefore discharging at the small end at speed V + S. Disregard friction. I have supposed the tube to taper "very gently," partly in order to be able to assume that the speed of the stream without the tube is in all parts practically = V, and its pressure consequently uniform. To enable the water from the tube, with its enhanced speed V + S, to discharge against this uniform pressure, the loss of head—

$$= \frac{(V + S)^2 - V^2}{2g}$$

due to this gain of speed, must be somehow restored to it, and we may imagine this effected by an infinite series of thin pistons in close succession, fed in at the large end, contracting in diameter as they pass along, and abolished as they emerge at the small end, each actuated by a small force in the direction of flow, sufficing at each point to just restore the head lost. The pressure will then be everywhere uniform, so that the tube would be inoperative and might be discarded; and if we imagine the whole system to be advancing at speed V (so that the outside water becomes stationary), we shall have an example of an ideal propeller with purely internal acceleration, as is contemplated by the old treatment. The aggregate thrust on the pistons will be measured by the momentum due to the change of speed S, and may be expressed according to the usual formula as—

$$T = \frac{W}{g} A\, V\, S.$$

The total work expended, namely, that of (in effect) pumping the whole quantity of water A V against the head—

$$\frac{(V + S)^2 - V^2}{2g}, \text{ will} = T \left(V + \frac{S}{2}\right).\ \dagger$$

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* See Appendix, §§ 27—29.

† For $W\, A\, V \times \frac{2\, V\, S + S^2}{2g} = T \times \frac{2\, V + S}{2}$.

§ 11. If, restoring the tube, we now imagine the entire restoration of head to take place at one point in the tube (see Fig. 2, Plate XXXV.), as by a succession of single pistons constituting a surface of change of pressure as previously supposed (see §§ 6 & 7), both the work expended by the "actuator" (as I will term the succession of pistons), and the thrust developed (by the whole system, viz., actuator and tube combined), will be unaltered, and this wherever the actuator may be placed.* True, the forward thrust on the actuator will be greater or less according as it is placed nearer the large or small end of the tube; but so also, and equally, will be the nett backward force on the inner surface of the tube, due to the consequent disposition of pressures within it. And this nett backward force will equal zero, and the forward force on the actuator will, therefore, equal the nett thrust T, if the actuator is placed at the exact point in the tube at which the speed $= \frac{S}{2}$.† All the foregoing reasoning, being based solely on a consideration of the speeds at the entrance and outlet and at the position of the actuator, is clearly independent of any question as to regularity or otherwise of the character of the taper of the tube, provided, as already noticed (§ 10), that the shaping is everywhere gentle enough not to sensibly affect the external pressures.

§ 12. So long, then, as the actuator is situated at the point where the speed—

$$= V + \frac{S}{2}$$

the thrust of the system is exactly that of the actuator alone, and so far as fore and aft force is concerned, the tube is inoperative. But it still performs the duty of resisting the surplus of external pressure before the propeller, and of internal pressure behind it; and in order to place ourselves in a position to remove the tube, and so make the final step to the conception of the surface of change of pressure advancing in open water, considered in §§ 7—9, we must first render the tube wholly inoperative, by so regulating its taper that the resistance it now affords to the external and internal pressures, may be supplied by the curvatures of the streams both within and without the tube; the resistance to the defect of pressure in front by inward acceleration, and the resistance to the excess behind by retardation of the inward velocity required. The shape which the outline of the tube and the lines of the streams will thus acquire must be something such as I have attempted to indicate in Fig. 3.‡

§ 13. Before pausing to consider certain difficulties of detail which this conception presents, we may observe that the steps by which the conception has been reached afford a clue to the conditions which determine how far ordinary propellers must approximate to this conception, in virtue of operating by what I have termed external rather than internal acceleration. We see that in an open propeller (as contrasted with

* See Appendix, § 30. † Ibid. ‡ See Appendix, § 31.

a closed propeller, such as a jet or turbine) some degree of defect of pressure in front, and excess of pressure behind, is an indispensable instrument in effecting the contraction of the column with its attendant curvature of streams; and in so far as this condition exists, there must be something in the nature of external acceleration. The contraction of the column, and the external acceleration, are, in fact, concomitant effects of the pressure gradients. And the shorter relatively to its diameter is the length of column pervaded by the thrusting action of the propeller, the more acute will be the contraction, the steeper, therefore, the pressure gradients, and the greater the external acceleration relatively to the total. In a screw propeller of ordinary proportion of length to diameter, it would seem that practically the whole acceleration must be external, and that in this respect the screw must approximate closely to our ideal conception of the advancing surface of change of pressure. Professor Greenhill's paper of last year shows how a screw may so operate, but my remarks on this head I reserve for my paper on Professor Greenhill's theory, and confine the present paper to the consideration of direct-acting propellers.

§ 14. But I am also indebted to Professor Greenhill's paper for the clue to the solution of a serious *primâ facie* difficulty in the strict conception of the advancing surface of change of pressure, namely, the supposition of the uniform finite difference of pressure on the two sides of the surface, extending absolutely to its very edge. The solution is that *at* the very edge the streams may be supposed to receive the finite change of speed instead of its equivalent in change of pressure. Now, although in the course of its passage through the infinitesimal thickness of the surface of change of pressure, the column, as a whole, cannot undergo the contraction of area corresponding to a finite change of speed, the infinitesimal annular elements at the edge may do so, and, in fact, will tend to do so, in virtue of the curvatures of the streams necessary to satisfy the differences of pressure. The effect upon the streams will thus shade off, by intermediate gradations, from one of pure change of speed at the very edge, to one of pure change of pressure at a finite distance within it. This circumstance, which, in our extreme case, strictly applies only to an infinitesimal outer layer of the column, will have a finite counterpart in the case of a propeller operating throughout a finite length of column.*

§ 15. The foregoing explanation also serves to suggest an instructive definition of the distinction between the "race" or portion of the column behind the screw, and the water outside it. In considering the contracting current, which I have attempted to indicate in Fig. 3, Plate XXXV., one is at first inclined to confuse it (at least, I myself was so) with a mere general vortex, created by the propeller, affecting all the water within a considerable distance, in the same way, and only in a gradually varying degree.

* See Appendix, § 31.

This idea at once prompts the question, if so, can we say that the column set in motion by the propeller has any precise sectional area, or any precise speed? Can we suppose that there is a hard and fast line of demarcation between the moving column and the stationary outside water? Or will not the speed rather shade off from the centre, indefinitely, to zero somewhere in the surrounding water? And what, then, becomes of reasoning based on sectional area of column and speed communicated to it? The answer appears to me to be that, barring effects of friction and viscosity, we can, and on our assumptions we must, suppose that the final speed of the column is uniform throughout its section, and that immediately outside its boundary the speed of the water will be zero, (or will be that of the undisturbed water, if we suppose for convenience that the propeller is stationary, and the body of undisturbed water flowing towards and past it). And this discontinuity of speed at the boundary of the column must exist all along it, as far forward as the very edge of the propelling surface. For all the streams composing the body of water in front of the propeller, or outside the race behind it, are subject to this common condition, that, originating in the undisturbed water, where they have common pressure and the common speed V, any subsequent local excess or speed must be attended by an equivalent sacrifice of pressure, and *vice versâ*. And the streams composing the race are subject to the same condition, but with this difference; that in passing through the propelling surface they have received either an augment of speed without sacrifice of pressure (as at the extreme edge), or an equivalent augment of pressure without sacrifice of speed; so that the pressure datum (or "potential," as it is termed), to which their relation of speed to pressure is henceforward to be referred, has been alike increased by the amount equivalent to the increase of speed from V to V + S. It is this inalienable elevation of rank (if I may so express it) which will afterwards distinguish the streams composing the race from those outside it, and whence it must arise that wherever the race streams and outside streams have the same pressure (as they must where they actually adjoin), they must have a corresponding difference of speed; and far astern, where the pressure of the undisturbed water must be everywhere resumed, the whole of the race must be travelling with speed S, in reference to the surrounding water.*

§ 16. The fact that in reality the fluid friction will in a great degree defeat this supposed condition, does not invalidate the reasoning based on the final dimensions and speed of the ideal race, because the thrust arises not from the race itself, but from the conditions which, except for friction, would generate it, of which the ideal race is used simply as a convenient measure.

§ 17. The conception of ideal propeller which we have thus closely examined, has been (to myself at least) an important step in the comprehension of the *modus operandi*

* See Appendix, §§ 31, 32.

of propulsion. And ideal as it is, it is in a valuable way complementary to the equally ideal conception on which the older treatment is based. The case of any ordinary open propeller must lie between the two extremes. And the determination of thrust from both treatments would be identical, except that in the older treatment it has been customary to reckon the quantity of water acted upon, as the area swept through by the propeller, multiplied by $V + S$, instead of $V + \frac{S}{2}$;* a difference which is trivial compared to the defect common to both treatments, for quantitative purposes, of dealing with a complete column instead of with the masses acted upon by the individual floats or blades. But the value of both treatments is illustrative, much more than quantitative.

§ 18. The new treatment, by showing that, of the total thrust and corresponding momentum generated, a portion must generally consist in a region of defect of pressure in front and of excess of pressure behind, corresponding to external acceleration, has provided a logical foundation for the old belief referred to above in § 3, as against the seemingly contrary contentions of Professor Cotterill's paper. The difference is indeed one of principle rather than of fact, because in the screw (with which in practice we are almost solely concerned), Professor Cotterill recognises a source of reduced pressure in advance of the screw, in the centrifugal action of the rotation of the race. This must, of course, in some degree modify the disposition of pressures and the manner of contraction of the column, in a way which I have not yet investigated; but at present I see no reason for supposing that it will vitiate the proposition that when the whole acceleration is external, one half must take place before and one half behind the propeller. Neither have I as yet seen my way to investigating whether this equality between the precedent and subsequent accelerations may be vitiated by an obstruction in front, such as the full stern of a vessel (see § 2). That such a condition must in a special degree subject the stern to the diminished pressure in advance of the propeller, and must by the consequent augmentation of resistance demand increased thrust, and, therefore, increased total difference of pressure, is of course evident; but whether it will place a larger share of the corresponding acceleration in front of the propeller is another question. Professor Cotterill's inference that a propeller situated near the greatest section of a vessel (as the paddles in a paddle ship), will, so far as pressures are concerned,† diminish resistance rather than augment it, is, of course, strengthened rather than weakened by the substitution of my view for his.

§ 19. In support of the propositions which I have cited above, in § 2, Professor Cotterill appeals to the case of a paddle working in a canal of definite sectional area, where he shows that the whole of the general water level behind the paddle will be

* See Appendix, § 33.

† Side paddles, of course, tend to augment resistance by the friction of their race against the ship's side.

higher than that in front of it by an amount which he terms y, and which is dependent on the slip ratio and the proportion of the sectional area of the race to the remainder.* But such general difference of level before and behind a propeller becomes infinitesimal in open water, as he shows; and he appears to base his argument on an analogy between the differences of general level incidental to a general current past a propeller in a close channel, and the local differences incidental to an analogous local current presumed to exist in open water. If, in pursuance of this analogy, we are to represent the local differences of level in open water by the general differences in a close channel, it seems to me unreasonable to select in the latter one of the two extremes of general level, instead of an intermediate level, as representing the general undisturbed level of the open water. But the truth is, that while the general differences of pressure are incidental simply to the degree of ultimate contraction of the column relatively to the size of the channel, the local differences are incidental to a condition which is not taken account of in the canal treatment, namely, the rapidity with which the contraction is effected, and the consequent curvatures of the streams, as I have illustrated in §§ 12 and 13.

§ 20. To the validity of the inference as to the effect of obstruction of flow to the propeller, based by Professor Cotterill on the canal analogy, I make certain additional objections in the Appendix to this paper.†

§ 21. In the reasoning which I have employed in this paper, it has for the most part been tacitly assumed that the propeller is working at such a depth below the water surface that the surrounding disturbances of pressure do not extend to the surface in any material degree. And the reasoning will correctly apply to the case of a propeller working close beneath the surface, as an ordinary screw, or at the surface, as a paddle wheel, at very low speeds. The differences of pressure will then satisfy themselves by small corresponding differences of surface level which will not materially alter the stream lines. But at higher speeds the differences of level will be greater, and will be modified by the laws of wave motion, and thus complicate the operation in a way which, I must confess, I am not at present prepared to specify, even did space permit. The effect, whatever it may be, though all important in a paddle-wheel, will clearly be slight in a properly immersed screw; but as yet I see no reason for supposing that the effect will, in either case, be of a nature to vitiate the apparently almost fundamental equality between the precedent and subsequent accelerations.

§ 22. As to the effect of the interaction of the respective wave-forming operations of hull and propeller to increase or diminish the total loss by wave-making, I fully agree with Professor Cotterill. The effect must be precisely analagous to the interaction of the wave-forming operations of the fore and after bodies of a ship, which I

* See Appendix, §§ 34—40. † Ibid.

have drawn out in my paper of 1881, "On the Leading Phenomena of the Wave-Making Resistance of Ships." The action of the propeller will increase or diminish the total power consumed in wave-making, according as the wave series which it would independently form is coincident or dissident with that which would be independently formed by the ship.

§ 23. The foregoing effect, and the kindred one referred to by Professor Cotterill (which I am inclined to include with it), of "throwing additional water into a state of wave motion," in virtue of the contraction of the column, will, as he points out, operate only at wave-making speeds. But the operation considered by Rankine, in his paper of 1865, which Professor Cotterill treats as equivalent to this, appears to me to belong not to wave-making proper, but to the quasi-wave motion involved in the stream-line replacement behind the hull, which would exist at moderate and low speeds. In the paper itself Rankine speaks only of "disturbed water," or water "that has been set in motion by the vessel"; and although in his reply on the discussion he speaks of the "wave of replacement," the context seems to show that he regards this as a state of motion which, "if the vessel is properly proportioned," does not cause resistance unless meddled with by the propeller.* His argument is, in effect, that since the forward motion of the water at the propeller is incidental to the motion of the ship past it, the forward momentum of the artificial addition to the quantity of water so set in forward motion, which will be demanded, as he considers, by the slip of the propeller, must involve a corresponding resistance to the ship.

§ 24. But, although Rankine appears to intend this reasoning to apply to stream-line motion, I think it clear that it cannot legitimately be so applied, and that it properly applies only to the case of "dead" water; that is to say, water which in losing its speed past the vessel, has by eddy action already parted with the corresponding energy.† Where, as in stream-line motion proper, the lost speed has been simply exchanged for an equivalent in increased pressure, the legitimate inference appears to be that the nett loss of energy arising from the propeller working in the slowed streams is *nil*, the loss by augmentation being balanced by the gain due to diminished apparent slip‡—a conclusion which accords remarkably with the results of experiment.

§ 25. I am not without hope that a well-studied application of the stream-line theory, aided, perhaps, by the conception of the operation of propulsion which it has been the main object of this paper to put forward, may enable us to make a distinct advance in the theory of propulsion, by placing this and other kindred propositions on a sound theoretical basis.

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* See Appendix, §§ 41 and 42. † Ibid. §§ 43 and 44. ‡ Ibid. § 45.

APPENDIX.

§ 26. The following symbols are used throughout the Text and Appendix :—

V = sternward speed of whole body of undisturbed water relatively to propeller.

S = additional sternward speed imparted to the column passing through propeller. [∴ final sternward speed of column relatively to propeller = V + S.]

v_1 = sternward speed of column relatively to propeller, at the point of passage through it (when all the acceleration is "external." See text, § 8).

A = sectional area of column before disturbance by propeller.

Q = quantity of water per second passing through propeller. [∴ Q = A V.]

W = weight of one cubic foot of water.

T = forward thrust of propeller.

[Speeds in feet per sec.; dimensions in feet; weights and forces in lbs.]

§ 27. (See text, § 9.)

(*a*) Regard propeller as stationary. Then total work of propeller ($= T v_1$) = total energy imparted to column, $= \frac{(V + S)^2 - V^2}{2g} \times W Q$;

$$\text{also, } T = \frac{W Q S}{g}$$

$$\therefore v_1 S = \frac{2 V S + S}{2} \qquad \therefore v_1 = V + \frac{S}{2}.$$

(*b*) Regard undisturbed water as stationary. Then useful work = T V; total work = $T v_1$; ∴ work expended in slip = $T (v_1 - V)$. This must equal energy represented by column running at final speed S, *i.e.*, $= \frac{W Q S^2}{2g}$

$$\therefore \frac{W Q S}{g}\left(v_1 - V\right) = \frac{W Q S^2}{2g}, \qquad \therefore v_1 - V = \frac{S}{2}.$$

The first of the above two forms of proof is, perhaps, the most apposite to the proposition as presented in the text, where we are not considering efficiency, and are primarily concerned only with the effect of the propeller on the column of water.

§ 28. The proposition, in one form or other, has been long known; and though ignored in Rankine's I. N. A. paper of 1865, it is recognised in his article in *The Engineer* of January 11, 1867.* Here he represents the theoretical loss by slip as $= T \frac{S}{2}$, but assigns to a common paddle-wheel or a screw without "gaining pitch" an additional equal loss, due to what he terms "suddenness" of change of speed of water. I find that my father, the late Mr. W. Froude, in a correspondence with

* See Professor Rankine's Miscellaneous Scientific Papers, p. 544.

Rankine about this article, took exception to the term "suddenness," on the ground that the particles of water are in fact set in motion, not "suddenly," but gradually, by the stream-line influence of the advancing float or blade, before it actually reaches them. Moreover, water cannot, like a soft solid, immediately absorb energy in impact, hence it is certain that whatever loss by slip there may be in addition to the theoretical value $T\frac{S}{2}$, must be at first represented by speed imparted other than purely sternward. This, indeed, we see to be partly the case in paddle-wheels, which send up vertical jets behind the floats. But it is evident that in so far as a propeller operates by "external" acceleration (as the present paper appears to show that all propellers must partly operate, and the screw almost wholly so), in so far is there less room for any loss by so-called "suddenness."

§ 29. But, indeed, I am inclined to go further, and, acting on the hint conveyed in my father's letter already referred to, to decry the supposed loss by "suddenness" as to a great extent a bug-bear. It is, I think, commonly supposed, for instance, that, as Rankine puts it,* in order to avoid loss from "suddenness," the propeller must be accurately contrived, so as "to act on each particle of water with a velocity at first simply equal to the velocity of feed V, and gradually increasing *at a uniform rate*" (my italics) "up to the velocity of discharge V + S." But take the case of the deeply immersed plate referred to in the text in § 6, acted upon by the force T for a (short) time $= t$ acquiring in that time the speed $= v$ (say), and consequently moving for that time at a mean speed $\frac{v}{2}$. The distance moved will be $\frac{t\,v}{2}$, and the work expended $= T\frac{t\,v}{2}$ This is admitted. But now, suppose that the force $= 10$ T during the first tenth part of the time t, and $= 0$ during the remainder. The speed will then $= v$ during this remainder of the time; the mean speed over the whole time will be nearly $= v$, and the distance moved nearly $= t\,v$. True, but during the last nine-tenths of the distance there will have been no force operating. Under the force 10 T the distance moved will be only $= \frac{t\,v}{20}$, and the total work expended will be only $T\frac{t\,v}{2}$, as before. By similar reasoning we may prove that, however irregularly the force acts, and however irregular be the consequent rate of acceleration, the total work expended will be the same as if the force and rate of acceleration were uniform. I am assuming that the force is never great enough (relatively to the depth of immersion) to cause a cavity at the back of the plate, a limitation which is, of course, very important in paddle-wheels. But here, the loss which results is to be properly ascribed, not to mere "suddenness," but to the circumstance that any force at all is brought to bear before the float is properly immersed.

§ 30. [See text, § 11, and Fig. 2.] The total work expended is measured simply by the quantity pumped by the actuator, into the head against which it is pumped; and the nett forward force of the system as a whole is measured simply by the quantity dealt with, into the speed imparted. None of these conditions are affected by the position of the actuator in the tube. But the thrust of the actuator itself is measured by the difference of pressure, into its area, and this must be equal to the nett thrust of the whole system, when

$$\frac{W\,A\,V\,S}{g} = A\frac{V}{v_1} \times W\frac{(V+S)^2 - V^2}{2g} = W\,A\,V\,S\frac{2V+S}{2g\,v_1};$$

i.e., when

$$v_1 = V + \frac{S}{2}.$$

* See Professor Rankine's Miscellaneous Scientific Papers, p. 545.

§ 31. [See text, §§ 12 to 15.] It is with considerable diffidence that I have in these paragraphs ventured on so far definite a specification of the conditions of operation of our imaginary advancing surface of change of pressure. I must admit that the step which we take in § 12, by introducing the accentuated contraction of the stream within the tube, falsifies some of the conditions tacitly presupposed in the case represented in Fig. 2; with this consequence, in particular, that the surface of pressure must evidently become dish-shaped instead of flat, if the streams are to traverse it normally at all points. But with this proviso, the reasoning appears to hold, because the complete column may be treated as a faggot of infinitesimal columns, each truly conditioned like that within the pipe in Fig. 2; except that the pipe has become curved instead of straight, a difference which will be unimportant so far as the internal flow is concerned.

§ 32. Again, the condition ascribed to the race in § 15, viz., that of one stream flowing within another of lower "potential," though theoretically possible, is I believe unstable, and the race would therefore tend sooner or later to break up and become interspersed with the surrounding water, as it undoubtedly must do in fact, through friction. But the argument of § 16 appears to sufficiently meet this objection.

§ 33. [See text, § 17.] By both treatments the thrust is equal to $\frac{W Q S}{g}$. But in the older treatment Q is taken as equal to P (V + S), when P = area of propeller disc. In my treatment—

$$Q = A V, \text{ and } P = A \frac{V}{v_1} = A \frac{V}{V + \frac{S}{2}}. \qquad \therefore Q = P\left(V + \frac{S}{2}\right).$$

§ 34. [See text, §§ 19 and 20.] Professor Cotterill puts the case of a paddle working at the surface of a parallel and level canal, along which water is flowing towards the paddle from in front of it in a single feed current of speed V, and away from it behind in a twofold current, comprising the "race" at the surface, of speed v, and the under current, of speed u. Barring friction, this conception is, of course, perfectly legitimate; but if, as is tacitly assumed by Professor Cotterill, and postulated by his equations, the speeds V and u are to be regarded as uniform throughout the depths of the currents of which they are predicated, we must, in strictness, assume that the operation of the paddle, which is the source of the change of speed from V to u, is extended over a sufficient length of the canal to affect the under current equally through its whole depth. Otherwise, besides the general difference of pressure before and behind the propeller given by the equations, we should have the local differences which I have investigated in the text of this paper, attendant on "external acceleration."

§ 35. Slightly modifying Professor Cotterill's notation, I put—

y = the elevation of surface behind the paddle, above that in front of it.
s = the depth of the race (of speed v).
d = the depth of the under current (of speed u).

I also put

$$\frac{V^2}{2g} = H; \quad \frac{u}{V} = \gamma; \quad \frac{(v - V)}{V} = \sigma,$$

(this last as put by Professor Cotterill, σ being the slip ratio expressed not in the usual form).

§ 36. The ruling conditions are: (1) That the race and under current must, between them, carry away the exact quantity of water brought by the feed current; (2) that y should satisfy the change of speed of the under current from V to u. Hence we get:—

$$v\,s + u\,d = \mathrm{V}\,(d + s - y);$$

Whence,

$$\frac{\sigma\,s}{d} = 1 - \gamma - \frac{y}{d}, \qquad (1)$$

Again,

$$y = \frac{\mathrm{V}^2 - u^2}{2\,g} = \mathrm{H}\,(1-\gamma^2), \qquad (2)$$

Combining (1) and (2), we get—

$$\frac{\sigma\,s}{d} = 1 - \gamma - \frac{\mathrm{H}}{d}\,(1 - \gamma^2); \qquad (3)$$

Also,

$$\frac{y}{\mathrm{H}} = \frac{\frac{\sigma\,s}{d}\,(1 + \gamma)}{1 - \frac{\mathrm{H}}{d}(1 + \gamma)} \qquad (4)$$

§ 37. This last equation, if written—

$$y = \frac{\sigma\,s\,\mathrm{H}\,(1 + \gamma)}{d - \mathrm{H}\,(1 + \gamma)}$$

is identical with Professor Cotterill's approximate equation for y, taking, as he does, $\frac{y}{s}$ and $1 - \gamma$ as negligible. But this approximate form seems to me to mask the significance of the result, and indeed to be scarcely legitimate, seeing that $1 - \gamma$ can never be less than $= \frac{\sigma\,s}{d}$. See equation (3). The import of the above equations (3) and (4) is best exhibited by the diagram in Fig. 4, which shows the varying values of γ and y for varying values of $\frac{\sigma\,s}{d}$ and $\frac{d}{\mathrm{H}}$.

§ 38. The diagram shows, in the first place, as is also obvious from equation (3), that if $\frac{\mathrm{H}}{d} = 0$, $\gamma = 1 - \frac{\sigma\,s}{d}$, whence u must necessarily be less than V. The sense of this result is that, if the speed is so low that y becomes infinitesimal compared to s, the combined sectional areas of the race and under current being practically equal to that of the feed current, any excess of speed of the race must be compensated by defect of speed of under current; and it is easily seen that the same conclusion would apply to any speed, if the surface of the canal were closed over, so as to prevent the actual change of surface level.

§ 39. But with surface open, and at speed high enough for $\frac{\mathrm{H}}{d}$ to become important, there enters, in addition to the solution analogous to that just described (*i.e.*, with γ less than 1), a possible *alternative* solution with γ greater than 1 (*i.e.*, with u greater than V), and y consequently negative.

The sense of this alternative solution is that the negative value of y suffices to so starve the sectional area of the race by denuding the paddle, as to demand an increased instead of diminished speed of under current, to carry away all the water.

§ 40. In this case, Professor Cotterill contends that the acceleration from V to u, with an attendant lowering of surface level, will commence in advance of the paddle, and he thence infers an analogous reduction of pressure in advance of a screw propeller, the flow towards which is impeded by the full run of a ship. But to this inference I make the following objections: (1) The supposed antecedent acceleration and fall of level cannot occur, consistently with the assumption noticed above, at the end of § 34. (2) The solution with u greater than V is at best only an alternative solution. (3) This alternative solution is incidental solely to a denudation of the propeller (see foregoing section), which has no analogue in a properly immersed screw.

§ 41. [See text, §§ 23 and 24.] The passage in Rankine's remarks in the discussion of his 1865 paper, referred to in the text, runs thus: "... regarding the effect of a propeller working in water which follows the vessel. That motion of the water always produces the loss of thrust and the waste of power which I have stated agreeably to the principles laid down in the paper, so long as the forward motion of the particles of water is due to what Mr. Scott Russell calls the 'wave of replacement,' which follows the vessel. ... Those particles of water are in the act of following the vessel in a wave that supports her stern, if she is properly proportioned, so that the wave does not lag behind her; the particles will then describe a certain curved path, after describing which they will be left behind nearly in a state of rest."

§ 42. The kind of forward motion, then, which Rankine describes as being that referred to in his paper as a cause of waste of power if interfered with by the propeller, is a transitory phase of motion, ceasing with the passage of the vessel, leaving the water at rest, and therefore absorbing no energy and causing no resistance; and not a wave motion proper, which is an essential cause of resistance, in that it leaves the water in motion. Neither is it (in Rankine's view at least) of the nature of the forward current due to eddy-making or friction, which is left behind in a continuous moving column, increasing in length as the ship progresses. Yet it is precisely this latter kind of forward motion to which, and to which only, the reasoning employed in Rankine's paper legitimately applies. We may follow this most conveniently, if, without pursuing Rankine's method *verbatim*, we suppose the following case.

§ 43. Let the passage of a vessel through the water at speed = V, impart to a quantity of water per sec. = q, the forward speed = U, and leave it with that speed. Then, undoubtedly, the vessel must thereby experience a sternward reaction = $\frac{W}{g} q\,U$. The work which she performs per sec. in travelling at speed V against this force, = $\frac{W}{g} q\,U\,V$; but the energy represented by the motion imparted to the water = $\frac{W}{2g} q\,U^2$. And this is precisely the condition of the "wake" due to eddy-making and friction, in which the difference of these two energy expressions, viz., = $\frac{W}{g} q\,U \left(V - \frac{U}{2}\right)$, is represented partly by increased temperature and partly by the eddying motion which the current possesses in addition to the mean speed U. In fact, of the whole power expended by the ship in

producing the current, only the small fraction $= \frac{U}{2V}$ remains in it in the shape of steady speed, and therefore capable of utilisation; the rest is gone beyond recall. A propeller working in this forward current will profit by the consequent diminution of apparent slip, and so utilise this small residue of available energy; but if, as is certainly the case when the propeller is working in "dead water," as *e.g.*, immediately behind a square sternpost, it at the same time increases the quantity of water to which the forward speed U has to be imparted by the ship, by an amount say $= q_0$, it will thereby cause an additional resistance to the ship $= \frac{W}{g} q_0 U$. This will demand an additional expenditure of power $= \frac{W}{g} q_0 U V$, which (with the exception at most of the small fraction of it $\frac{U}{2V}$) will be represented by additional heat and eddy-making in the wake.

§ 44. The value q_0 must of course depend on the nearness of the propeller to the eddy-making features, a point which Rankine does not notice; neither does he touch on the form assumed by the wasted energy (an important point, as will presently appear); in other respects his reasoning is faithfully reproduced in the foregoing paragraph, which applies strictly to the forward current produced by friction or eddy-making. But if we suppose the forward current U to be only a transitory incident in a stream-line system, which leaves the water at rest behind it, the conditions are entirely altered. For the missing energy, $\frac{W q U}{g}\left(V - \frac{U}{2}\right)$, is now converted, not into heat and eddies, but into pressure,* by means of which pressure the water is ultimately restored to rest; (or, as is perhaps more convenient to treat it, to the full speed V past the ship, in place of the reduced speed $V - U$), and the resistance $\frac{W}{g} q U$ exactly counteracted. And since the system of which the transitory current U forms part is one in itself involving no resistance, there is no reason why an increase of the volume involved in such system (if the propeller does so increase it) should introduce resistance. At any rate, since there is now no question of work wasted in eddies or heat, if we are to suppose any work to be wasted in virtue of the circumstance that the propeller is working in the forward current, we must suppose that waste work to be represented by an additional (sternward) speed of race over and above that which it would have in still water; an effect which it is certainly a paradox to attribute to the forward current.

§ 45. The presumption appears to be on the contrary that the conditions which, in the absence of the propeller, would have increased the speed of the water flowing through its vacant place from $V - U$ to V, will, in fact, increase the speed of the race flowing from the propeller, from $V - U + S$ to $V + S$. It would thus seem that the final speed of the race, and consequent waste of power represented by it, will be simply the speed due to the slip S which it would have in undisturbed water; and that, consequently, the *primâ facie* gain to the screw from working in the forward current, must have just compensated for the augmentation of resistance.

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* $\frac{W q U}{g}\left(V - \frac{U}{2}\right) = W q \left\{\frac{V}{2g} - \frac{(V-U)^2}{2g}\right\}$.

REMARKS ON PROFESSOR GREENHILL'S THEORY OF THE SCREW PROPELLER.

By R. E. Froude, Esq., Associate Member of Council.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 12th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

§ 1. The distinction between the new theory of the screw propeller suggested by Professor Greenhill in his paper of last year, and that propounded in these Transactions by Professor Rankine in 1865, which, with slight modifications, has till recently remained the accepted theory, appears to centre in this; that whereas in the latter the propeller is regarded as directly imparting to the column of water on which it operates a spiral motion—in other words, a motion partly sternward and partly rotary—in the former it is regarded as directly imparting a rotary motion only.

§ 2. The momentum due to imparting the spiral motion contemplated by Rankine, maintains a corresponding spiral force; and this is resolved into two component forces, an axial component or thrust, and a rotary component or turning moment. Or, equally, the spiral motion may be itself resolved into two component motions, one axial and the other rotary; and the momentum due severally to the two component motions, may be regarded as severally maintaining the two component forces. This is merely an alternative way of stating the same proposition.

§ 3. Professor Greenhill, on the other hand, propounds the ideal case of a screw propeller working within a close-fitting cylindrical tube, which tube, by preventing any contraction of the column in passing through the propeller, thereby prevents any change in its axial speed. The propeller then imparts to the column a purely rotary motion, the momentum due to which maintains a rotary force; and this rotary force, acting on the oblique blades, involves an axial component or thrust, which, in the absence of change in axial speed of water, can be balanced only by a difference of water-pressure before and behind the propeller.

§ 4. The change of axial speed within the length of the propeller, which is contemplated by Rankine's treatment, and excluded in Professor Greenhill's, implies, as just hinted, a corresponding contraction of column within the same distance, a

supposition which becomes unreal in proportion as we suppose the propeller to be short relatively to its diameter. If, as an extreme case, we imagine a screw having multitudinous thin blades of only infinitesimal length in line of motion, (a screw, in fact, of which the solid of revolution becomes a mere disc of infinitesimal thickness), it is clear that within that infinitesimal thickness no contraction of column corresponding to a finite change of speed can take place. And unless we are prepared to contend that the operation of an ordinary practical screw propeller has nothing whatever in common with that of the extreme imaginary screw just supposed, the practical relevance of Professor Greenhill's treatment must be admitted.

§ 5. Rankine's implied hypothesis that the whole thrust is represented by an axial speed directly imparted to the column within the propeller, applies strictly to one ideal case. Professor Greenhill's hypothesis that no axial speed is directly so imparted, applies strictly to another ideal case ; and these two ideal cases are opposite extremes, contrasted with and complementary to one another. The method by which in his own ideal case Professor Greenhill determines the thrust and corresponding difference of pressure before and behind the propeller, I have already incidentally noticed ; but the same result may be instructively approached by another track, and the two ideal cases instructively contrasted, as follows.

§ 6. For simplicity, let us here consider not a complete screw, but a mere annular element of a screw, of radial thickness infinitesimal relatively to its radius, which will, therefore, impart motion not to a solid column of water, but to a thin zone or tubular column.

§ 7. If we commence by supposing this elementary annular propeller, not to form part of a complete propeller, but to be operating independently in open water ; and if, further, we suppose the radial thickness of the annulus to be small relatively to its axial length, we then not only may, but must, suppose that the general water-pressure is the same before as behind the propeller, and that any thrust or axial force maintained by the propeller is represented by the momentum due to an axial component of speed imparted to the tubular column of water in the course of its passage through the annular propeller. Accordingly, we must imagine the interior and exterior bounding surfaces of the annulus to be not cylindrical, but slightly conical in opposite directions, so that its radial thicknesses at entrance and exit may be inversely proportional to the axial components of speed of entrance and exit, which we will term V and $V + S$ respectively. The form of cross-section in plane of axis and radius which is thus assumed by the annulus is shown in Fig. 1, Plate XXXVI.

§ 8. The section along its mid-cylindrical surface, showing the oblique blades, appears in Fig. 2, Plate XXXVI. The water is supposed to be frictionless, and the blades perfectly thin and very close to one another (relatively to the length of the annulus), in

order to ensure that the whole tubular column of water shall assume a homogeneous spiral motion. The successive blades, together with the interior and exterior bounding surfaces of the annulus, may, in fact, be regarded as constituting a tissue of small pipes of nearly * rectangular section through which the water is flowing.

§ 9. For convenience, we may regard the annulus as stationary, and the water flowing towards it and into it, with the speed and spiral direction denoted by the line N (see Fig. 2), having axial component V, and from it and out of it with speed and direction denoted by X, with axial component V + S. The water-pressure being the same before as behind the annulus, the speed of flow along the line of each pipe must be the same at entry as at exit, hence the speed of exit X must equal the speed of entry N, and the change in value of axial component from V to V + S must arise purely from the change of direction. Hence, also, the normal cross-section areas of the pipes must be the same at exit as at entry, a condition which necessarily arises out of the geometry of the case, in virtue of their change of direction. For in virtue of this, their normal width is greater at exit than at entry, in the ratio $\frac{V + S}{S}$, while their depth, viz., the radial thickness of the annulus, is less in the same ratio.

§ 10. Completing the construction in Fig. 3, Plate XXXVI., where B D E G is a parallelogram, of which the sides are all equal alike to N and X, it is at once seen that the diagonal B E, bisecting the angle D B G, represents the speed and direction of the resultant motion imparted by the propeller in virtue of the change in direction of flow, and that of this resultant motion, S and R are severally the axial and rotary components. Then if A be the aggregate sectional area of entry of the annulus (measured in plane of rotation), the quantity of water dealt with per second = V A, and the resultant and component forces severally maintained by the momentum due to the resultant and component motions, will be equal to $\frac{W}{g}$ V A, multiplied by the several speeds B E, S, and R. Thus we have—

$$\text{Spiral resultant force} = \frac{W}{g} V A \times B E.$$

$$\text{Thrust or axial force } (= T) = \frac{W}{g} V A S.$$

$$\text{Rotary force } (= F) = \frac{W}{g} V A R.$$

$$\text{Tan } \theta \left(= \frac{F}{T} = \frac{R}{S} \right) = \frac{V + \frac{S}{2}}{C - \frac{R}{2}};$$

* Truly rectangular if we regard radius as infinite relatively to distance of blades apart.

where—

θ = the mean effective angle of blade with plane of rotation, and
C = the circumferential component of the speed N.

This, of course, is only a slightly modified version of the propositions underlying Rankine's formulæ.*

§ 11. But if we now suppose the annulus to form part of a continuous tissue of similar elements extending outwards and inwards for a radial distance infinitely great relatively to the axial length, the assumed contraction of radial thickness of the annuli becomes no longer possible. The radial depths of the rectangular pipes being therefore now constant, their normal sectional areas at entry and exit will be directly, and the speed of flow through them inversely, proportional to their normal widths. Hence, if we suppose that in passing through the annulus the direction of flow is changed from that of G I to G K (see Fig. 4, Plate XXXVI.), the speed must be changed in the ratio I K : L J, or (by similarity of triangles), the ratio G I : G J. Thus we may take G I as representing the direction and speed of entry N_1, and G J that of exit X_1. The axial component of both speeds is v_1, and the actual speed imparted, in virtue of the change from G I to G J, is the simple rotary speed R = I J.

§ 12. The diminution of speed from N_1 to X_1, in the course of the passage through the pipes, can only be rationalised by supposing that the pressure behind the propeller into which the pipes are discharging is greater than that in front of it from which the pipes are receiving. In this reduction of speed from N_1 to X_1, we therefore find an independent witness to the relative excess of pressure behind the propeller, which Professor Greenhill recognises as the source of the thrust.

§ 13. The value of this increase of pressure will be—

$$\frac{N_1^2 - X_1^2}{2g} \times W;$$

and if the area on which it operates to produce thrust, namely, the area of the annulus in plane of rotation, be termed A_1, we get for the thrust T—

$$\begin{aligned} T &= \frac{W}{2g} A \, (G\,I^2 - G\,J^2) \\ &= \frac{W}{2g} A_1 \left\{ C^2 - (C - R)^2 \right\} \\ &= \frac{W}{g} A_1 \left(C - \frac{R}{2} \right) R \end{aligned}$$

* See Appendix, § 25.

For the rotary force F, we get—

$$F = \frac{W}{g} A_1 v_1 R.$$

Whence—

$$\frac{T}{F} = \frac{C - \frac{R}{2}}{v_1}$$

Accordingly, for the effective mean blade angle θ with the plane of rotation, we get—

$$\text{Tan } \theta = \frac{v^1}{C - \frac{R}{2}}$$

thus agreeing with Professor Greenhill's determination of the effective mean pitch ($= \lambda$),* for the case where the blades are curved from the angle of entry of the water to the angle of exit. My reasons for preferring to confine my treatment to this case, I state in the Appendix.†

§ 14. In the reasoning which I have embodied in the geometry of Figs. 3 and 4, I have endeavoured to present, side by side, and treated on studiously parallel lines, the fundamental propositions appertaining to the respective treatments of Professors Rankine and Greenhill; and we may now proceed to examine the relation between them. I hardly think I correctly follow the meaning of Professor Greenhill's general remarks on this head, in the opening of his paper, which, indeed, appear to me to do an implied injustice at once to Professor Rankine's theory and to his own. He says (Trans. I.N.A., 1888, p. 319): "In reading Professor Rankine's paper, . . . we shall find that the propulsive effect of the propeller is calculated as due entirely to the backward slip or motion imparted to the water, the rotatory or transverse slip being considered as so much wasted power; while Mr. Lamport would seek to inquire what proportion of the propulsive effect is due to the rotatory motion imparted to the water. This is what we shall attempt to determine in this paper." And, again (Ibid. p. 320): "Now, as Professor Rankine and the other writers have calculated the propulsive effect of the screw propeller from the backward slip, leaving out of account as so much waste the rotatory motion imparted to the wake, *it will at least be permissible*" (my italics) "to reverse these assumptions," &c.

§ 15. Now, I must confess I do not follow the application of these remarks to the relation between the respective treatments of Rankine and Greenhill. I do not see how in Rankine's treatment the rotatory motion can be legitimately said to be "left out of account," or to be "considered as" anything except precisely what it is.

* See Appendix, § 26.

† Ibid., §§ 27 to 29.

Neither do I see, on the other hand, that in Professor Greenhill's treatment there is any omission or faulty assumption which needs to be palliated, so to speak, by an implied *tu quoque* addressed to the upholders of Rankine. Each treatment appears to me to be undeniably sound on its own merits, and without reference to the other.

§ 16. I quite agree, if this is what is meant, that the relevance to practical problems is imperfect in both treatments individually, in so far as the mechanical conceptions to which they strictly apply are ideal extremes; and that the complementary character* of these ideals confers upon the theories a special conjugate revelance. But Professor Greenhill's words, above quoted, appear to mean more than this, and to suggest that in neither treatment are the assumed dynamic conditions quite correctly taken into account; and this I do not admit.

§ 17. In Rankine's treatment, the rotatory slip is certainly in one sense "considered as so much wasted power," but so also, equally, is the axial slip, and both rightly. Both are essential sources of waste of power, are alike indispensable instruments in the development of the axial thrust, and as such are duly and completely taken into account. That, in order to maintain a force in a given direction by action on a fluid, a counterpart motion must be imparted to the fluid in the precisely opposite direction, is a first principle in dynamics; and the principle holds equally, whether the force and counterpart motion are simple, or are the corresponding components of an oblique force and oblique counterpart motion.

§ 18. And this principle, of course, applies to the conditions assumed in Professor Greenhill's treatment, equally with those in Professor Rankine's. In both alike, the thrust, or axial component of force, *must* be ultimately satisfied by a counterpart axial component of speed imparted to the column; the only difference is that whereas in the one this axial acceleration is, strictly speaking, regarded as occurring wholly within the propeller, in the other it must occur wholly without it. In the latter, the thrust is indeed satisfied immediately by the difference of pressure on the two faces of the propeller, but this difference of pressure must in turn be satisfied by an ultimate axial acceleration of the column, corresponding to the axial force.

§ 19. The conditions of this, as I have termed it, "external acceleration," I have attempted to examine, in my paper "On the Part played in Propulsion by Differences of Fluid Pressure." It must here suffice to point out, that of the total axial acceleration S, one-half must occur before the propeller, in obedience to defect of pressure in front of it, and the other half after it, in obedience to excess of pressure behind it. Thus, the axial speed of column through the propeller, v_1, in Fig. 4, must

* See below, § 22.

equal $V + \frac{S}{2}$; V, as in Fig. 3, being the speed relatively to the undisturbed water. This proposition follows from the, on our assumptions, necessary condition that the work wasted in slip must exactly equal the kinetic energy of the motion imparted to the column. (See Appendix to the above-mentioned paper, § 27.)

§ 20. The value of S requisite to satisfy the axial component T, must equal $R \frac{T}{F}$ or $= R \operatorname{Tan} \theta$, as in the Rankine treatment exemplified in Fig. 3. Bearing this in mind, and also that the v_1 of the Greenhill treatment in Fig. 4, equals $V + \frac{S}{2}$, we may conveniently and strikingly exhibit the true relation between the two treatments, by superposing Figs. 3 and 4, as shown in Fig. 5. Then, A_1 being the uniform sectional area of the Greenhill propeller taken in plane of rotation, and A that of entry of the Rankine propeller, if we put $A\,V = A_1 \left(V + \frac{S}{2}\right)$, it is evident that for common values of V, C, and θ, both propellers will have common values of S and R, and therefore common thrust and rotary force.*

§ 21. In other words, for given quantity of water dealt with, given speed of advance relatively to undisturbed water, given circumferential speed, and given mean blade angle, there is no difference whatever between the two treatments, in respect of the motions ultimately impressed on the water, forces yielded, work expended, useful work, and efficiency. The sole difference of operation is one of intermediate mechanism, and consists in this, that in the one the whole angular divergence of the water, or effective slip angle, occurs within the propeller, in the other only that portion of it corresponding to the rotary element of the slip.

§ 22. This conclusion illustrates the significance of what I have termed the conjugate relevance of the two contrasted treatments, in virtue of the complementary character of the ideal extreme conceptions to which individually they strictly apply. For, since the same formulæ† apply to both extreme cases, we may infer that they also apply to the intermediate cases to which ordinary screw propellers more nearly correspond.

§ 23. Thus far we have confined ourselves to considering a single annular element of a screw propeller. If we conceive a complete propeller to be composed of a series of annular elements, all having the same mean blade angle θ, and all revolving at the same circumferential speed C, (and therefore at angular speeds varying inversely as the radius), we shall, of course, have the same component motions imparted to the

* See Appendix, § 30.

† That is to say, assuming that the expressions for area of propeller are so contrived as to correctly measure the quantity of water dealt with. In the Rankine treatment the area should be taken as the harmonic mean of the assumed areas of entry and exit.

water, the same thrust per unit of area in plane of rotation, and the same efficiency, in all parts of the screw. But if we assume that in all parts, the angular velocity is the same, and the mean blade angle such as to give the same mean pitch, the thrust per unit of area in plane of rotation will, as Professor Greenhill points out, decrease as we approach the axis. The thrust will be measured by S, and for the varying value of θ for varying radius, with constant mean pitch λ, and revolutions per minute $= n$,

$$S = 2\,(n\lambda - V)\cos^2\theta.^*$$

§ 24. This variation of S in different parts of the disc, as well as the centrifugal action of the rotation of the race, must modify the stream-lines of the contraction of column, to which I have made reference in my other paper; also, conversely, the action of the blades will be modified by that contraction; for, at the moment of passing through the screw, the column, being in the middle of the process of its acceleration and attendant contraction, is in the act of contracting at its most rapid rate, and the particles are flowing along convergent instead of axial lines. These operations, therefore, taken together, will complicate the problem in a way which I cannot profess to have fully considered. At any rate I will not attempt to examine these operations in the present paper; and, from a practical point of view, it would seem that these operations must be of secondary importance; since their effect is probably small in comparison with that of the changes in condition involved in passing to a propeller of ordinary type, from the ideal conception of a many-bladed or very lengthy propeller, which must form the basis of any treatment in which a homogeneous motion is supposed to be imparted to a continuous column of water.

APPENDIX.

§ 25. (See text, § 10.) If λ = the pitch corresponding to the mean blade angle θ, and n = the number of revolutions per minute, then, by the geometry of Fig. 3,

$$n\lambda = V + \frac{S}{2} + \frac{R}{2}\tan\theta$$

$$= V + \frac{S}{2}(1 + \tan^2\theta) = V + \frac{S}{2\cos^2\theta}$$

The efficiency, barring friction, $= \dfrac{V}{n\lambda} = \dfrac{1}{1 + \dfrac{S}{2V\cos^2\theta}}$,

which is in accordance with Rankine's result, that the loss by slip is increased by obliquity of blade

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* For $n\lambda = V + \dfrac{S}{2\cos^2\theta}$, see Appendix, § 25.

in the inverse ratio of the square of the cosine of the angle. Rankine, it is true, makes the power wasted in slip $= \frac{T\,S}{\cos^2\theta}$, instead of, as here, $\frac{T\,S}{2\cos^2\theta}$, because he assumes blades of uniform pitch, instead of curved from angle of entry to angle of exit. Hence he gets waste of power in slip equal to twice the kinetic energy represented by the speed imparted to the column, the extra half of which loss, in his article in *The Engineer* in 1867*, he attributes to what he terms "suddenness." For remarks on this head see the Appendix to my other paper, "On the Part played in Propulsion by Differences of Fluid Pressure;" and for my reasons for adhering to the curved blade treatment, see below, §§ 28 and 29.

§ 26. (See text, § 13.) If p be the "leaving pitch," as in Professor Greenhill's notation, then, since

$$\frac{C}{n\,p} = \frac{C - R}{v_1}$$

$$\frac{C}{n\,\lambda}\left(= \frac{C - \frac{R}{2}}{v_1}\right) = \frac{1}{2}\left(\frac{C}{v_1} + \frac{C}{n\,p}\right)$$

$$\therefore \quad \frac{1}{\lambda} = \frac{1}{2}\left(\frac{n}{v_1} + \frac{1}{p}\right)$$

which is Professor Greenhill's equation for λ.

§ 27. Since $F\left(C - \frac{R}{2}\right) = T\,v_1$, and the total work expended $= F\,C$, the work wasted in producing the rotary † slip R

$$= F\frac{R}{2} = \frac{W}{g}\,A_1\,v_1\,R \times \frac{R}{2} = W\,A_1\,v_1\,\frac{R^2}{2g}$$

i.e. (as Professor Greenhill notices), equals the kinetic energy of the rotary speed R imparted to the race, which is the theoretical slip loss. The additional loss which Professor Greenhill, like Professor Rankine (see above, § 25), obtains on the supposition that the blades have uniform pitch p throughout, instead of being curved from angle of entry to angle of exit, as I have supposed, he attributes to "shock of impulse."

§ 28. To this term "shock," as to Rankine's equivalent use of the term "suddenness," I object—first, that water cannot, like a soft solid, immediately absorb the energy of a shock or impact; secondly, that the particles of water must in reality be diverted, not with a shock, but gradually by the stream line motion, in advance of the edges of the blades.‡ The supposed loss, if genuine, must at least in the first instance take the form of a motion of the race, or of parts of it, other than that on which the calculations of momentum are based; and thus a formal inconsistency is *primâ facie* introduced into the theoretical treatment.

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* See Professor Rankine's Miscellaneous Scientific Papers, p. 544.

† I say "rotary" slip because in the treatment of the complete efficiency there is an axial slip ($= v_1 - V$) to be also taken account of (see §§ 18 and 19).

‡ See Appendix to my other Paper, § 28.

§ 29. Moreover, the supposed loss is of a kind which I think may be fittingly classed with fluid friction and other kindred conditions, which in the present stage of the treatment are left out of account. I therefore think it justifiable, as it is certainly preferable on the score of consistency of theory, to adhere (as I have done in this paper) to such mechanical conceptions that the whole of the waste work may be strictly represented by the kinetic energy of the motions which are assumed to be imparted. From a practical point of view, an additional justification for this course is to be found in the circumstance that ordinary screw blades do, in fact, possess some degree of gaining pitch, in virtue of their roundness of back; while, on the other hand, the advertent adoption of a gaining pitch has not been found to noticeably increase efficiency.

§ 30. (See text, § 20). From the respective expressions already given for Tan θ for the two treatments, (§§ 10 and 13), bearing in mind that $v_1 = V + \frac{S}{2}$, we get for both treatments alike—

$$\text{Tan } \theta = \frac{V + \frac{S}{2}}{C - \frac{R}{2}};$$

and also in both alike—

$$R = S \tan \theta;$$

hence for given values of θ, V, and C, both treatments must give the same values for S and R.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Professor J. H. Cotterill, F.R.S. (Associate Member of Council): By the courtesy of Mr. Froude, I have been supplied with copies of these papers two or three weeks since. They cover so much ground that it is impossible to discuss them completely, and I shall confine myself to those points which either refer directly to my own paper, or which seem to me to have important practical application. First, with regard to the proposition number one, on the first page of the first paper. In my opinion the case of the paddle differs from that of the screw. In paddles the proposition, as Mr. Froude states it, is certainly not true. But in this case he has not quite apprehended my meaning, a misapprehension which is due, I think, entirely to my own unguarded language. As regards the screw, however, the conclusion I have come to is different from his. I think the proposition, as it stands, is correct for a screw with many blades. It only fails, as I pointed out in a passage quoted in Mr. Froude's footnote, with a screw of few blades, in which, as we know, strong suction takes place. I will now take the various points in order. The paddle-float, if not too deeply immersed, working, that is, under good conditions, sweeps off the surface water. Into the cavity, so to speak, thus created, the water rises from below. There is, therefore, a suction in front of the paddle-float—a local suction. I have never for a moment supposed it otherwise. What I meant to say was that the acceleration thus produced did not extend, when the paddle was worked to proper advantage, far in front of the paddle itself. The case I put was the case of a small boat lying in front of the paddle, and I said that if the paddle was working to advantage, the acceleration would not extend to the small boat. The resistance of the small boat would not be augmented. If the supply of water is obstructed, then the case is different. Mr. Froude objects, with perfect justice,

to my canal analogy, as being obscure. So no doubt it is, and I will change it for a better one. I will take an iron plate, and fix it horizontally below the paddle, so that it may extend from a point vertically below the paddle-shaft to some distance in front of the paddle. The effect of that will be that the water will no longer be able to rise up immediately in front of the float. The water, therefore, not being drawn from below, will be accelerated in front of the paddle, and the acceleration will extend to any distance that the plate extends to. Thus there will be a current of water, which will augment the resistance of the small boat. That was the action I had in my mind, and this illustration which I give shows that the effect of obstructing the supply is to transfer the suction of the paddle to some distance in front of the paddle. It was that which I attempted to illustrate, though very imperfectly, by my canal analogy. Now, Mr. Froude treats this question of the suction in front of the paddle in a very ingenious manner, which is purely original, and he adds to our knowledge a very important proposition, which is this, that in a direct-action propeller the section in front is equal to the thrust behind. In other respects I believe his view is entirely that of Rankine; it is only that he has, in a very clear and ingenious manner, succeeded in putting the question on a logical basis, as he very rightly says. Now, turning to the case of the screw, I am not able to agree with Mr. Froude's treatment. I do not see the connection between the "actuator" and the screw, and I think he hardly does justice to his own singularly ingenious conception of a surface of advancing pressure. I wish that he had explained to us more exactly how he intended the actuator to be applied to the case of the screw. My opinion is that the screw blade itself is the surface of advancing pressure in that case. For, consider the difference between the action of the screw, and the action of the paddle. The paddle drives the water directly before it, and changes the velocity of the water. The screw-blade cleaves the water, and divides the stream of water into two, one part passing behind the screw, the other part passing in front of the screw. Now its thrust is occasioned by deflecting these two streams of water. The stream of water that passes behind the screw-blade is deflected by the pressure of the screw-blade, which turns it through a small angle, called the "slip angle." The stream of water in front of the screw in like manner is deflected through nearly the same small angle, and this is done by a minus pressure, on the front of the screw-blade, a suction, as we may more properly call it. That seems to be apparent from the nature of things, and we must regard the screw blade itself as a spiral surface of advancing pressure. We cannot replace it as in paddles by an ideal surface cutting across the stream. Next, on what does the magnitude of the excess pressure and of the suction depend? Evidently on the quantity of water in each stream and the slip angle or angle of deflection. If the two streams are equal, the suction will be equal to the thrust, but not otherwise. Now, if we take a long thin blade of slowly gaining pitch, there will evidently be approximate equality, because the same quantity of water passes on each side of the blade, one in front, and the other behind, and therefore the thrust in that case equals the suction. Again, since there is minus pressure in front, and excess pressure behind it, the particles of water will be retarded as they pass behind the screw blade, and they will be accelerated as they pass in front of the screw blade, and, therefore, if I understand Mr. Froude's phraseology correctly, I should say that the acceleration of the water is for one stream external, and for the other internal. Well now, evidently the thrust behind the screw blade accelerates the water, and drives it forward, which it does by first of all increasing the pressure until it leaves the blade, and then by what Mr. Froude calls external acceleration, accelerating the water. On the other hand, the suction in front of the screw blade draws the water from the stern of the ship. It draws the water forwards, and accelerates it. I say, therefore, that in a screw with few blades the suction of the blades draws the water forwards, and produces a current of water through the blades. If on the other hand, we have a screw with many

blades, the ideal tubular gaining pitch screw, which Mr. Froude considers, I say then that with the small stream of water passing between the two blades there will be suction on one side, and thrust on the other side, so that the acceleration of one half of the small stream, and the retardation of the other half in passing through the blades, will counterbalance one another, and no effect will be produced on the motion of the whole. Mr. Froude has not given any reason so far as I can see for supposing that, in a multiple-bladed screw, apart from centrifugal action, the water is accelerated in passing through the screw. The case I had in my mind when I wrote my paper was not a screw of gaining pitch, but a screw of uniform pitch, and, in my view, in that case the screw is partially choked, that is to say, not merely is there no acceleration, but it seems to me that the natural flow of the water is actually somewhat checked, because in the blade of uniform pitch the water all along the leading edge of the blade is brought to rest; relatively to the blade, the pressure is concentrated all along the leading edge, and the motion of the water is checked. The proposition that suction-thrust, however, seems to apply to each individual blade of a gaining pitch screw, as well as to Mr. Froude's case of the direct action propeller. But suppose that we have not a thin blade, but a blade of a certain thickness. The effect will be that the suction will not be equal to the thrust, because a different quantity of water passes behind the screw blade than passes in front of the screw blade. Take the case of the screw blade formed as in Mr. Calvert's experiments, in which one side of the blade was plane, and the other side was convex. It appears to me that the necessary effect of that, apart from the eddies that are formed, will be that the water is accelerated as it passes round the convex surface, and that must make the suction greater, and as eddies will certainly be formed there, it seems that the suction produced will be still greater. I think, therefore, that the suction will be proportionately much greater in a thick-bladed screw, and for that reason I think that the current of water passing through the screw must be greater, and that probably the augmentation due to a thick-bladed screw may be considerably greater. Rankine's theory of the screw, as applied to the case of a blade of uniform pitch, appears to be based on two distinct hypotheses—first, that the velocity of the water parallel to the blade is unaltered. Of course, as I pointed out in my paper of 1879, that is not true for individual particles, but it is true for the average motion of the water. The motion of the water parallel to the blade is unaltered. That is one hypothesis, and I think it must be one which is pretty strictly fulfilled, always supposing that the pressure in the race is the same as the pressure of the still water outside. Next it is supposed that the diameter of the race is equal to the diameter of the screw. Perhaps Rankine did not expressly state that anywhere, but it is implied in his mode of treatment that it is so. No doubt he knew perfectly well that the exact diameter of the column would be subject to variation from a variety of complicated causes which could not possibly be taken into account, and therefore he selected the case which most readily submitted itself to calculation, and the assumption is, I think, right. It is right, because the only use of Rankine's formula is to furnish us with a theoretical maximum for the thrust of the screw. The actual diameter of the screw column will probably be slightly less depending upon the amount of suction of the screw drawing water through it. To attempt to understand the question of obstructed supply in screws, I think we ought to resort to the same device as we employed just now in the case of paddles, that is to say, to imagine a casing surrounding the screw, and between the screw and the vessel. The effect of that will be to prevent the screw drawing any water from outside. It can only then get its water through the casing. The effect of that will be twofold. In the first place, the diameter of the screw column will be diminished, because the screw cannot get so much water; and in the second place, the pressure in the casing will be lowered in consequence of the suction. The first of these facts I did

not recognise when I was writing my paper of 1887, but it is evident it ought to be recognised as an effect of obstructed supply. That influence acts to diminish the thrust of the screw. In the second place, the low pressure existing in the casing, in my opinion, must have the effect of altering the working of the screw. The working of the screw is no longer the same as it would be in open water. The difference of pressure between the casing and the race has the effect of altering the proportion between the rotary velocity and the sternward velocity of the water passing through the screw. That is the action which I attempted to illustrate in my paper. Of course it is a question how far the full stern of a vessel is represented by this ideal casing. That may legitimately be doubted, but this I do say, as I said in my paper, that the reflex action of the vessel upon the working of the screw is a thing which ought to be considered. It ought not to be taken for granted that the working of the screw is exactly the same in the two cases. Next as to augmentation, it is natural to assume in that particular case of the casing that the augmentation of the thrust of the screw will be equal to the augmentation of the resistance of the vessel, but I did not mean to assert that that would necessarily be so in all cases. It seems to me that the remarks which Mr. Froude makes about augmentation form a valuable part of his paper ; I refer to the last article of the text of the paper, and the corresponding articles in the appendix, especially in relation to the question of efficiency. The question of the magnitude of the augmentation is something distinct from the question of the loss of efficiency as influenced by augmentation. Now, as regards efficiency, the old view of Rankine was that in all cases the working of a screw in disturbed water was a cause of loss of efficiency. To modify that, first of all, the late Mr. Froude pointed out that when the screw worked in the frictional wake, there would be a gain of efficiency instead of a loss ; and the author of this paper, in his valuable paper of 1883, actually proved that by experiment. In a particular case he found a gain of efficiency of about 8 per cent. from working in disturbed water, due no doubt to the action of the frictional wake. Next as regards working in stream water Rankine's idea was that that was a loss also. In the remarks made by Mr. Froude, in which I am disposed to concur, he says, that there is neither a gain nor a loss, and that is a highly important conclusion. In the case of eddy water, as was I think first pointed out by the late Mr. Froude, there will certainly also be a loss. There is, therefore, a distinction between the three cases of the frictional wake, the eddy water, and the stream water. As regards the question of thickness, I pointed out just now that it seemed to me that the screw will have a very much stronger suction with a thick blade than with a thin one ; and hence the question of thickness may be, perhaps, a question of great importance, because it may increase the augmentation. Now, we may ask ourselves with regard to the thick-bladed screw, this question : In a thick-bladed screw the normal pressure on the blade is increased, and the tangential pressure on the blade is also increased by the thickness. Now, the efficiency of the screw taken alone as regards friction, depends upon the ratio of these two qualities. Evidently, however, there must be a great dissipation of energy in a thick-bladed screw by eddies, but what becomes of the energy so dissipated, since the efficiency of the thick-bladed screw may be not very different from the efficiency of the thin? I answer that perhaps it may be due to increased augmentation, that this kind of augmentation may represent loss of efficiency. Thus I come to the conclusion that the efficiency of the screw may, perhaps, be very much affected by this question of thickness of blade, a view already expressed by Mr. Calvert in some remarks which will be found in Volume XXVIII. page 169, remarks with which I was not acquainted when I made my observations on Mr. Calvert's paper read a few months later. I should have been glad if time had permitted me to discuss many other points, but will now only thank Mr. Froude for the interest he has taken in my paper, and say I think he has given us a most valuable contribution.

Professor A. G. Greenhill (Visitor) : My Lord and gentlemen, I beg to express my pleasure

that so distinguished an authority as Mr. R. E. Froude should have undertaken to continue the theory of the screw propeller, a subject which is so peculiarly his own by inheritance and by professional occupation. I have read his paper with great interest, and I find it full of suggestive theories. For my part, I must acknowledge the justice of his criticisms on the paper I had the temerity to bring before this Institution last year, for now I see clearly a great many defects which I shall be pleased to have an opportunity of correcting. At the outset, I should have called my paper "A mode of presenting the theory of the screw propeller," instead of "A theory of the screw propeller." Those who have studied Rankine's classic paper of 1865 will agree with me, I think, in saying that it is a very difficult one to read; and, for my part, I found his theory much simplified by reversing the order of his procedure. Instead of beginning, as Rankine has done, by calculating the thrust from the backward momentum imparted to the race, and thence deducing the turning couple of the engines, to my mind it seemed a simpler procedure—first, to calculate the rotation of the wake from the velocity of the water as it leaves the propeller; then, secondly, to calculate the angular momentum, and thence the turning couple of the engines; thirdly, to deduce the thrust from the turning moment by the principle of virtual velocities; and, lastly, to attempt an investigation of the pressure in the propeller wake. This should be equivalent to looking at the propeller primarily from the point of view of the engines, and not from the point of view of the ship. Turning to Mr. Froude's Fig. 3, this would be equivalent to taking into account the component which is there marked R, which is the component of the motion felt by the engines in turning the propeller, and, considering the part played by the motion which is due to R, before considering the part of the motion which is due to S, the component of the motion which accelerates the race. The relation of R to S is, of course, a matter of geometry, depending upon the pitch of the propeller. If we assume there is no change of pressure, we immediately find ourselves with the formulæ calculated by Rankine, enunciated in Article 1 of his celebrated paper on the "Theory of Propellers." But this principle of Rankine treats the water as if it was a cloud of dust or fine particles, in which the pressure may be taken throughout as zero. We have, however, to deal with water where the only limiting condition is that there should be no sudden change of pressure, and where, as Professor Cotterill mentioned, there may exist a very great amount of suction equivalent to negative pressure in the wake. Considering that the dynamics of the screw propeller and of the turbine can be rendered identical, I thought it would be instructive in presenting the theory to lead off with the case of a turbine employed as a screw propeller, presenting the theory in a manner which, to my mind, seemed more simple, and thus to delay to some extent those delicate considerations of the stream lines, and of the distribution of pressure in the race which have engaged the consideration of Professor Cotterill and Mr. Froude. These considerations should, in my opinion, be presented last in the theoretical explanation of the screw propeller. The change of momentum and the change of pressure are the two causes at work in obtaining propulsion. To my mind it is instructive to discuss a case in which the second question only operated, and to compare it with the theory of Rankine, in which the first cause alone is considered.

Mr. J. I. Thornycroft (Vice-President): My Lord and gentlemen, in the first place it is my duty to recognise, and this I do with great pleasure, what Mr. Froude has done for us in presenting to us the theories of Professors Rankine, Cotterill, and Greenhill, in a manner which shows clearly their relation to each other, and that there are a number of views from which the screw may be regarded. These views at first sight appear to contradict one another, but the result of Mr. Froude's work is to show that these different theories are simply different views of the same thing, all true for the

limited view they take of the action of the screw propeller. These theories may all be reconciled, and all are required to build up a theory of the screw propeller. In fact, that theory is not at present complete, and I hope to bring to your notice an idea which represents, I think, another step in the correct theory of the screw propeller, but not conflicting, as it would at first appear, with what has already been done. In the papers Mr. Froude read (and I am indebted to him for having had a copy of them for some time), the demonstration he has given us of the action of a propeller in the accelerating stream is so clear and beautiful that I cannot express anything beyond the admiration I feel. So long as the propeller was within the tubes he describes, we were somewhat on common ground, but this tube being gradually moulded to a form in which it was no longer necessary, and then taken away, helps us to realise a conception which would be otherwise, perhaps, too difficult. I feel indebted to Mr. Froude for building up my ideas so firmly thus far that I venture to make another step, which I trust will be found correct. The proofs Mr. Froude brings to support the propositions he makes seem beyond dispute, and I am glad it is only where he ventures beyond the solid ground of his reasoning, and does not see, in the idea vaguely suggested by Professor Cotterill, of reduced pressure in advance of the screw, due to the centrifugal action of the rotation of the race, any cause for supposing that it will vitiate the proposition that when the whole acceleration is external to the propeller, one half must take place before, and one half behind, the propeller. Professor Cotterill does not seem to have carried this idea further, and expresses an opinion that when many thin blades are used this cause of loss of pressure will not exist, but argues in favour of a loss of pressure due to a few thick blades, and would also associate a loss of pressure forward of the propeller with the obstruction caused by the full run of the ship propelled. As the paper before us excludes such considerations, and is one treating the subject in an ideal manner, I think I shall be more in order in taking entirely the ideal course, although the want of apparent agreement between Mr. Froude's deductions and some experiments I have made with the guide-blade propellers associated with my name led me to think that something must be wrong, for, to put it familiarly, Mr. Froude was apparently claiming for the open propeller a result which could be only obtained, I believe, with one in which special means are provided to secure the acceleration taking place within the propelling apparatus. Mr. Froude's instrument, although a propeller, and admirably adapted for his demonstrations, is no common propeller, and is an actuator, which does what is required, and nothing else; it exerts pressure only perpendicularly to its own disc. It, therefore, gives no rotation to the water acted upon. What I have to describe requires that the water acted upon should have also rotation, and I would introduce to Mr. Froude another instrument, which, only having power to cause rotation of the column of water passing through it, may be placed close to Mr. Froude's actuator without in any way disturbing the action of his instrument, but will give equal angular motion to the entire column that has passed through it, although its thickness may be less than any assigned limit. This I will call a gyrator. When the action of this instrument is combined with that of Mr. Froude's actuator, by varying the energy of action attributed to each, the result may be made to coincide very nearly with the action of what might be described as perfect screw propellers of different pitch ratios, having their blades so thin as to cause no obstruction, and so narrow and numerous as to occupy no perceptible length in the direction of the axis. I would now wish to centre the ideas on what is called the screw race, or more properly a revolving frictionless column of water, which we may imagine to have a definite cylindrical surface. Let this column revolve between two discs, which are prevented from moving, and let the column revolve throughout its length, as throughout its section, at an equal angular velocity; its surface will then be in equilibrium, and may be assumed to have the same surface pressure as the water surrounding it. But let us examine its interior. First, near the surface,

within it, is a small defect of pressure. This increasing rapidly at first, as we enter, gradually falls to the lowest point at the axis. The result of this is, the discs secured at the two ends tend to approach each other by a definite force depending upon the square of the velocity of the surface of the revolving cylinder of water and the area of the end of the cylinder. It is the effect of the operation of this force originating in rotation, and changing to some extent the phenomena so beautifully described by Mr. Froude, of which I now wish to speak. Imagine my gyrator fixed in space, and an indefinitely large stream of water flowing around and through it at the velocity V; it offers no resistance, the whole stream is undisturbed. Let it now cause rotation of the water passing through it, and supplemented with one of Mr. Froude's actuators of the same diameter. Let us again consider the race produced by the gyrator alone. Before, we considered this race as bounded at the two ends by discs resisting other water from entering the ends, and increasing the volume of the race. If the gyrator is advancing continually into new water, and lengthening the race at the rule V, the loss of pressure within the race will cause water to flow through the instrument at a velocity greater than V, and this will be an acceleration before the propeller, causing an apparent slip, although the only motion impressed on the water directly by the instruments has been at right angles to the axis of the race. This apparent slip constitutes the essence of that to which I wish to direct your attention, and, as may be afterwards seen, may be positive or negative—the sign depending on the condition as to whether rotation of the race is considered, or rotation of the stream on its way to the propeller's disc. This latter idea, in which the acceleration caused by the revolving stream is negative, although purely an ideal one, is the most easy to conceive, for by giving the gyrator power to rotate all the feed-water, and at the same time, if we entrust to Mr. Froude's actuator the difficult task of changing this rotation into difference of pressure, making at the same time this change without loss of energy, we shall have, under these conditions, a perfect propeller, for there will be no acceleration of the race, and all the energy expended in rotating the water by the gyrator will be converted into useful work by the actuator. But we must now endeavour to examine what takes place as we approach possible conditions of working, and if the action of the gyrator be at first considered still as influencing the feed-water, but not as finding all the energy. Under this condition the race will be accelerated, having some value greater than V, which is understood to represent the initial velocity of the feed-water; and as the action of the gyrator is diminished, we approach the condition examined by Mr. Froude, in which there is no rotation either before or behind the propeller, this condition forming one that may be considered as central between the two extremes of the action under examination, the region of real propellers being, unfortunately, I am afraid, all included in the space on the side where the efficiency is less than it is in this centre, where no rotation is given to either the feed or race. If the race is made to revolve at first slowly, the loss of pressure in the race may be considered as reducing the pressure on the back of Mr. Froude's actuator, and reducing by an equal amount the propelling effect obtained, and, therefore, if we so regulate the action of our instruments that the speed of the race remains constant, while the pressure on the back of the actuator is entirely lost, we shall find that the acceleration is now all forward of the propeller, the actuator working on a stream having the velocity $V + S$ instead of $V + \frac{S}{2}$. The propeller has now lost in two ways from effects which may be attributed to the rotation of the race. The slip is increased, while at the same time the propelling effect is diminished. I therefore take it that this rotation of the race must be included in any complete theory of the action of the screw propeller, which necessarily creates a revolving race. And it seems to me that the expenditure of energy by our ideal propeller may be simply expressed for conditions including rotation of the feed-water of the race. The energy expended, E, must equal

the useful work + the energy found in the race. Call the latter E_A, and I find—

$$E_A = E_a \pm E_r$$

E_a being the energy given to the water by the actuator, and E that communicated by the gyrator, the sign used depending on the rotation being before or behind the propeller, the sign + belonging to the latter. The total energy expended may be thus expressed—

$$E = U + E_a \pm E_r$$

in which U represents the useful work.

Major N. Soliani (Member): My Lord and gentlemen, I do not wish for one moment to enter into the merits of Mr. Froude's paper, because I am not able to do so. I simply wish to mention a fact which has a little bearing on the subject. It refers to the action that the hull at the stern part of a vessel exerts on the screws. We have in the Italian Navy two small twin screw ships, the *Folgore* and the *Saetta*, of about 350 tons displacement, which are exactly alike, so far as engines, hull, and propellers are concerned, the only difference being that in the latter ship the dead wood at the stern has been cut off; but on the measured mile trials, although they were tried under exactly the same conditions, the results were entirely different. On the *Folgore* the screws were harder to drive, and the apparent slip very much less. The power necessary to drive the two ships was, for equal speeds, larger in the *Folgore*, up to a speed of 18 knots, within which limits the efficiency of propulsion of the *Saetta*, which has no dead wood, appears to be the best. The superiority of the *Saetta's* performance is specially apparent at the lower speeds, fading gradually away as speed increases, and for speeds above 18 knots the *Folgore* takes the advantage. The performance of the two ships at very low power shows that the initial friction of the engines is somewhat larger on the *Folgore*, but although it may explain why the performance of the *Saetta* was comparatively better at the lower speeds, it does not seem to be sufficient to account for the entire phenomena, over which the difference existing in the two ships at the stern part of the hull has probably a great influence. I wished to lay these facts before you because probably Mr. Froude will give the clue to phenomena which I have not been able to explain.

The President: Gentlemen, I have an appeal to make to you. Mr. Froude is obliged to catch a train at 5.50. Will you allow him to make what few remarks he has got to make. They are not many. I do not want to stop the discussion, but he is obliged to catch that train, and, therefore, I make that appeal to you, and I have no doubt you will grant it.

Mr. R. E. Froude (Associate Member of Council): At this late hour, and being pressed for time to catch a train, I will not attempt to deal in detail with the remarks which have been made in the discussion, and which, indeed, require to be carefully thought over. My principal object has been to draw attention to the ideal conception of the advancing surface of change of pressure which is represented in this diagram (Fig 3, Plate XXXV.), and to develop the conditions of its operations; and as I understand Professor Cotterill, he does not object to the legitimacy of this conception, as an ideal conception.

Professor J. H. Cotterill: As you state it—as an ideal conception—only to its applicability to the screw.

Mr. R. E. Froude: Precisely. The question is as to its relevance—to propulsion generally, and especially to the screw propeller. Now, it appears to me that the conception is relevant to the screw propeller; in so far as all the different blades of the screw may be regarded as acting in combination upon the same body or column of water; and for many reasons, which it would take too long to enter upon here, I believe that the screw blades, even in an ordinary screw propeller of only three or even

two blades, do so operate to a great extent. Professor Cotterill asks why I think that the effect of a screw can be that of the creation of a difference of local pressure in the column. Well, that appears to me to have been very clearly shown by Professor Greenhill's paper, and also by my modification of his treatment in this diagram (Fig. 4, Plate XXXVI.). The effect in question must clearly be produced in Professor Greenhill's ideal case, of the screw working in the closed pipe; and I do not see how in open water the immediate effect can be otherwise, if you have a series of annular propellers such as these (in Fig 4, Plate XXXVI.), a large series occupying a complete disc, but short enough in axial line to exclude any tangible contraction of column in passing through. If, in fact, we suppose that propelling surface (pointing to Fig. 3, Plate XXXV.) to be composed of infinite series of infinitesimal annular propellers of this kind, all revolving at the same circumferential speed, and having the same blade angle, so as to produce a uniform difference of pressure on the two sides of the surface so formed, I do not see how the effect can differ from that which I have represented in that diagram (Fig. 3, Plate XXXV.), except, indeed, in so far as it will be modified by the rotation of the race, and this is the point which I understood Mr. Thornycroft to be examining. I look forward with interest to reading his remarks, from which I think a good deal is to be learned. So far as I have followed Professor Cotterill's examination of the separate operations of the individual blades of the screw, I fully agree with his treatment, and quite endorse his view, that it is the surface of the individual blade which must be regarded as the true surface of change of pressure. But I certainly think, as I said just now, that in an ordinary screw the several blades operate to a great extent, not separately, but in combination on the whole body of water in front of them, and that in virtue of this circumstance, the state of things a little distance before and behind the screw must approximate closely to that indicated in Fig. 3, Plate XXXV. And by my second paper I have endeavoured to bring the two treatments into line by showing that the general result must be the same, whether we suppose that the thrust is immediately due to sternward motion directly imparted to the water, or to a region of difference of pressure created; because in the latter case, of the total sternward motion corresponding to the thrust, which must in any case be ultimately imparted to the water, one-half must be acquired before the propeller is reached. And thus the true theoretical slip due to the thrust will be experienced by the propeller equally, whether its immediate operation is one of change of speed or mere change of pressure.

The President: Gentlemen, it only remains for me to convey your thanks to Mr. Froude for his paper. Now, I think you will all agree with me, gentlemen, that the problems raised in a paper of this kind, which are the result of enormous expenditure of time and trouble, are really problems that can hardly, with advantage, admit of public discussion, because the fresh and tortuous problems which may be raised in these replies, you have the authority of Mr. Froude himself for telling you so, require an amount of brain work which it is impossible to apply to them on the spur of the moment. They must be studied in the study itself in order that efficient reply may be made to them. I do not know whether I convey exactly my own meaning, but that is my own feeling, and I rather think it is the feeling of a great many who are present here. But the value of these researches, of course, is inestimable in the present age where speed has to be attained on the laws of propulsion, but they are things that we cannot discuss off-hand. It is perfectly impossible to do so. I do not believe that the most accomplished mind can do it, and you have Mr. Froude's authority for what I say. Therefore, it only remains for me to thank him on your behalf for the time and labour he has expended upon this subject. He has fulfilled a promise made last year in the second paper to-day, and I am quite sure you are very grateful to him for the additional light he has thrown upon the subject, but there is a great deal more to be thrown yet, I think.

ON THE CONNECTION BETWEEN THE CURVE OF STABILITY AND THE METACENTRIC CURVE OR LOCUS OF PRO-METACENTRES.

By Professor P. Jenkins, Member of Council.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 12th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

That part of the science of Naval Architecture which embraces the statical stability of ships has been very fully discussed in this country from the time of Mr. John's investigation of the first curve of stability for H.M.S. *Captain*, down to the present day. The subject has been looked at and examined from a number of points of view, and a variety of methods of greater or less usefulness have been devised, both in this country and in France, to enable the calculator to deduce, with the least possible expenditure of labour, the data from which the necessary curves may be constructed. Indeed, this branch of the science of Naval Architecture has attracted the attention of so many able investigators, that anyone turning his attention to the subject now can scarcely hope to deduce anything that shall prove of far-reaching importance. Nevertheless, there remain, and I presume must always remain, some minor points that have either been overlooked by the pioneers of the science, or set aside by them in their eagerness to discuss matters of greater practical importance; these may now profitably receive attention, in order that our knowledge may be made the more sound and complete.

So far as the statical stability of ships is concerned, we occupy very much the position of gleaners, who, going over the ground from which the great bulk of the corn has been removed, are content to gather the stray ears which those who had been gathering sheaves had been unwilling in their haste to regard. But as many ears make a sheaf, so even minor points affecting the stability of ships have a value, and it is on this ground that I venture to call your attention to some points of interest in the connection between the ordinary curve of stability and the metacentric curve or locus of pro-metacentres, as it has been termed by Sir Edward Reed.

For a number of years I have been accustomed, in calculating curves of stability, to make use of the known height of the transverse metacentre above the centre of gravity in drawing in the curve so as to ensure greater accuracy in the early stages,

as well as to afford a check on the work, and I daresay others have done the same. For that purpose, in Fig. 1, Plate XXXVII., I set off along the base line O X an angle of 57·3°, the circular measure of which is unity, and erect an ordinate X A at the point X, whose length is equal to the metacentric height. I join O and A by a straight line, and the curve of stability, if correctly drawn, should be touched by O A tangentially at the point O. The accuracy of this construction will be seen at once if it be remembered that the righting arm for a small inclination θ from the position of equilibrium is G M·θ, for from Fig. 1, $\frac{G Z}{\theta} = \frac{X A}{1}$ by similar triangles, and since X A = G M, we have G Z = G M·θ as before. It does not, however, follow that the curve of stability lies wholly below the tangent O A; in fact, it seldom does so. Whether it does so or no depends, as we shall see later on, upon whether the metacentre rises in the vessel as she inclines, or whether it descends. But whatever be the path which M traces out as the vessel is inclined, it must always remain the case that the line O A is a tangent to the curve at the point O.

We have here, then, a very direct connection between the actual height of the metacentre in the vessel in relation to the centre of gravity and the direction which the curve of stability takes at its inception; and the question naturally arises whether any such connection continues to be maintained as the vessel becomes further inclined, and if so, by what law the connection may be expressed. As we shall see later on, a very specific connection, which is capable of being simply expressed, does exist at all inclinations.

Let me in the first place, however, direct your attention to the metacentric curve itself, and to the methods that have been employed in its construction. Messrs. White and John, in their admirable joint paper on the stability of ships, which has proved of very great value to students from the time when it was read before this Institution in 1871 down to the present day, were the first, I believe, to investigate this curve, and to discuss its properties. So far as I have been able to gather from the paper, their method of procedure was as follows: they availed themselves of the well-known fact that the metacentric locus is the evolute of the locus of the centre of buoyancy, and by setting off the values of the righting arm from the centre of gravity at the several inclinations for which their calculations had been made, after the manner of the polar diagram, they were enabled to draw the successive normals to the locus of the centre of buoyancy, thus forming the envelope of the metacentric curve, which could then be easily drawn in to touch those normals tangentially.

It would be difficult, however, by such a construction to locate the metacentre corresponding with a given water plane with any degree of precision. The actual positions of the cusps were obtained by direct calculation of the moments of inertia of the corresponding water planes which enabled the actual values of B M to be set off.

but this involved the determination of the precise position of the centre of buoyancy corresponding with each inclination, and this is not usually known, except in cases where the dynamical stability is estimated. At that stage this particular branch of the subject has remained, so far as I am aware, up to the present day.

I now want to show how the actual position of the metacentre corresponding with any inclination of a vessel may be obtained directly from the curve of stability. And here I ought to remark upon the use of the word metacentre in connection with an inclination of a vessel at which she is not in equilibrium, but subject to a righting moment of greater or less magnitude. Mathematicians have difficulty in following Naval Architects when they speak of a floating body having a metacentre in any condition other than that of equilibrium. I well remember the objection which a very able man, the Professor of Mathematics at the Royal Naval College in my time, offered to such a use of the word "metacentre," and the difficulty he experienced in appreciating the advantage of an extension of the meaning of the term beyond that given it in treatises on hydrostatics. Obviously the succession of points on the metacentric curve do not fulfil the definition of metacentre as usually given, but the meaning attached to them is one well known to Naval Architects. Moreover each such point may separately be made to rigorously comply with the definition by shifting cargo transversely until the vessel is brought to rest at any given inclination. The metacentre corresponding with such a position of rest is rigorously a metacentre according to the definition, and is a point on the metacentric curve.

Returning now to the consideration of the connection between the curve of stability and the metacentric curve, suppose the vessel in Fig. 2, Plate XXXVII., to be inclined at a definite angle θ from the upright or position of equilibrium. The righting arm is G Z and the metacentre M is on the metacentric curve. Let the vessel be now further inclined through a small angle $\Delta\ \theta$. The righting arm will change to G Z + Δ G Z and the small increment Δ G Z will be expressed by Z M $\cdot \Delta\ \theta$. Thus

$$\Delta \text{ G Z} = \text{Z M} \cdot \Delta\ \theta$$

and

$$\frac{\Delta \text{ G Z}}{\Delta\ \theta} = \text{Z M}$$

Proceeding to the limit $\frac{d \cdot \text{G Z}}{d\ \theta} = \text{Z M}$, or the ratio of the small increment of the righting arm to the corresponding small increase in the inclination is measured by the distance between Z and the corresponding metacentre.

If now we regard the curve of righting arm (Fig. 3, Plate XXXVII.) we see that since the ordinate at any inclination θ is G Z, $\frac{d \text{ G Z}}{d\ \theta}$ represents the inclination of the tangent to the curve of stability at that inclination. Hence if the metacentric curve be known, together with the actual position on the curve of the metacentre corresponding with

each inclination at which it is desired to obtain a spot on the curve of righting arm, we are in a position to determine not only the precise values of G Z at those specific inclinations, but also the direction which the curve takes at each inclination. Thus if Fig. 3 be the curve of righting arm for the vessel of Fig. 2, and we set off G Z at the inclination θ, from Z draw a line Z B parallel to the base line, having a length of 57·3°, which is the angle whose circular measure is unity, and from B erect a perpendicular B C equal to Z M to scale, and join C Z, the line so drawn will be tangent to the curve of righting arm at the point Z.

Conversely, having given an accurate curve of righting arm, we may proceed to construct the corresponding metacentric curve, locating upon it the metacentre proper to each inclination. To do this, draw tangents to the curve of righting arm at a series of inclinations, measure the rise or fall of each tangent over 57·3° on the same scale as that on which the curve of righting arm has been set off, and set each of these as an ordinate from Z at right angles to the corresponding G Z drawn as in the polar diagram. The locus of all such points is the metacentric curve.

I may be pardoned for introducing so simple a case as that of the circular cylinder (Fig. 4, Plate XXXVII.) by way of illustration. Here the metacentre for transverse inclinations is fixed at the centre of figure, and M Z = G M cos θ, while G Z = G M sin θ. G M cos θ is, therefore, the slope of the tangent to the curve of stability for such a floating body at the inclination θ. If now we regard the curve of stability itself, we shall have abscissa θ and ordinate y = G M sin θ. Hence—

$$\frac{dy}{d\theta} = \text{G M cos } \theta \text{ as above.}$$

For some time my students at Glasgow University have been accustomed to construct the metacentric curve in the above way, and when the curve of stability is calculated with care, and the spots not too far apart, the method yields accurate results.

The intimate connection between the curve of stability and the metacentric curve thus shown to exist throws a great deal of light upon some features of the curve of stability, and leads to some interesting conclusions. If the curve of stability rises above the tangent drawn to it at the zero of inclination, as it usually does, we know from the above that the metacentre at first rises in the vessel as the inclination grows. The maximum inclination of the tangent to the curve of stability will usually occur at that inclination of the vessel at which the water plane cuts the deck edge, and here we have a cusp in the metacentric curve. As the vessel continues to be inclined from the upright, Z and M approach each other until they coincide, after which M falls below Z, and Z M becomes negative. As applied to the curve of stability, these changes mean that the inclination of the tangent to the curve of stability decreases, until the tangent becomes horizontal, when the righting arm has a maximum value, and that after that

inclination has been passed the tangent slopes in the contrary direction, and continues to do so usually until after the curve crosses the base line.

At the inclination by which the righting arm is a maximum, $\frac{d\,G\,Z}{d\,\theta} = 0$, and hence Z M = 0, or Z and the metacentre coincide. Hence if we have the metacentric curve given, we may at once determine the inclination at which the righting arm becomes a maximum for any position of G by drawing from G a normal to the curve; this will be the maximum ordinate of the curve of stability, and Z will coincide with M. The same process will disclose a minimum value, if it exists. In the case of the vessels of the *Cyclops* class, to which I shall refer more fully later on, three normals may be drawn from G to the metacentric curve within a range of 11°, two giving maximum values, and the third a minimum. Obviously maximum and minimum values alternate.

By means of the above fact we may express in a more general form the condition necessary in order that the length of the righting arm may be a maximum or minimum. We know that the surface of buoyancy for a floating body being given, and also the position of the centre of gravity, positions of equilibrium occur at all inclinations at which normals drawn from G to the surface are vertical, those being positions of stable equilibrium for which G B is a minimum, and unstable for which G B is a maximum. If now we regard the surface traced out by M as the vessel is inclined normally in all directions about an horizontal axis through G, capable of moving up or down so as to maintain a constant displacement, the metacentric curve being simply the projection on a transverse plane of the path of M on that surface for transverse inclinations, and from the centre of gravity draw normals to this surface, it follows that at each of the inclinations for which the foot of the normal is a metacentre the length of the righting arm has a maximum or minimum value.

I referred above to a peculiar feature of the metacentric curve for the vessels of the *Cyclops* class. Those vessels have a central citadel, the effect of which is to cause the curve of stability to take the form of a camel's back, as shown in Fig. 5, Plate XXXVIII., the first maximum being attained before the central citadel enters the water. We have here two maximum values of the righting arm, and one minimum, and in consequence we are enabled to draw three normals from the centre of gravity to the metacentric curve.

The metacentric curve for this vessel, drawn as I have described, is given on Fig. 6, Plate XXXVIII., and an enlargement of that part of it with which we are dealing on Fig. 7, Plate XXXVIII. The first normal that can be drawn from G to the curve is G M_3, Fig. 7, Plate XXXVIII., and this is a maximum ordinate of the curve of righting arm. As the vessel continues to be inclined, the citadel begins to enter the water, and with this inclination the cusp M_1 corresponds. At this inclination I may here observe the slope of the curve of righting arm is a maximum. It may, moreover, be stated generally

that at every inclination at which the slope of the tangent to the curve of stability is a maximum, we have a cusp on the metacentric curve, because then Z M is a maximum. The entrance of the central citadel into the water causes the moment of inertia of the water plane to be increased, and the metacentre returns along the line $M_4 M_6$. To this branch of the curve a normal G M_5 may be drawn from G, and this normal is a minimum ordinate of the curve of stability. At the inclination at which M_6 is reached, the deck edge of the citadel enters the water, and the curve of stability has again a maximum slope. The metacentre next traces out the path $M_6 M_7$, which enables a third normal, G M_7, to be drawn from G, thus constituting a second maximum value of the righting arm of the curve of stability.

One word regarding the locus of Z shown on Fig. 7. This locus touches the metacentric curve tangentially at the three points M_3, M_5, and M_7, the two curves having a common tangent, viz., the normal through the centre of buoyancy at each of those points.

The fact that the inclination of the tangent to the curve of stability corresponding with any inclination of the vessel is measured by Z M alone, and is, therefore, independent of the value of G Z, leads to the interesting conclusion that wherever G be situated on the line G Z, Fig. 2, whether at G_1 or G_2, or elsewhere, the rate of increase of the righting arm at that particular inclination will remain unchanged. We change the absolute value of the righting arm by moving G along the line G Z, but not the rate of increase of righting arm with inclination. The slope of the curve at other inclinations than the one in question would, of course, be affected. From this it follows that it is impossible for a vessel to have a maximum righting arm at an inclination of 90°, no matter how low the centre of gravity may be placed, unless the metacentre at 90° inclination be in the middle line plane, or G be moved out of the middle line, the condition being that the line joining G and M shall be parallel to the middle line plane. In ordinary vessels M at 90° is usually much below the middle line plane. In the case of the circular cylinder, G and M satisfy the above condition at an inclination of 90°, since M remains fixed at the centre of figure, and in this case, as we know, the curve of stability does attain its maximum value at the above inclination.

DISCUSSION.

Mr. B. Martell (Vice-President): My Lord, I think that we ought not to allow this discussion to close without expressing our very high estimation of the work that Professor Jenkins is doing as a Professor in the University of Glasgow. He has recently read a most valuable paper at the Scottish Institution of Engineers and Shipbuilders in Scotland—a paper of very great importance indeed, affecting the stability of petroleum-carrying ships in bulk, of which we already have a great many, and of which a great many more are now building; and notwithstanding the Professor has taken a great deal of time to prepare that paper, it reflects the highest credit on him that he

still has managed to devote further time to the preparation of this most valuable paper, which has just been read before the Institution, where he first gained his laurels Under these circumstances, I think it is right that we should thus mark our appreciation of the service which he has rendered in preparing this paper for us on this occasion. I have nothing more to say than to express what I am sure is the feeling of every member of the Institution, how gratified we are to find, notwithstanding he is unable to attend these meetings, he still remembers the Institution of Naval Architects.

The PRESIDENT: Gentlemen, I rise to convey through the Secretary our thanks, and I am sure you will allow me to do so, to Professor Jenkins. I was particularly glad to hear our friend, Mr. Martell, who always thinks of absent friends, say what he did about Professor Jenkins. I am delighted at the success which he has achieved, as I took very great interest in him when he left this part of the world, and I did what little I could to assist him in getting the post which I think he is so thoroughly suited to fill. I am very pleased indeed to see that he is able to find time to remember the Institution in which he made his mark, and to prepare for us a paper of this value in the midst of his other educational duties. I know the esteem in which he is held in Glasgow, and I congratulate him heartily on the mark which he has made there. I am sure that wherever Professor Jenkins is he will make his mark. I am extremely glad to endorse fully and entirely the kind remarks made by Mr. Martell in reference to Professor Jenkins, and our Secretary will convey the expression of your thanks to him for contributing to us his most valuable paper.

SOME DETAILS RELATING TO THE CORRECTION OF COMPASS ERRORS IN IRON VESSELS.

By W. W. Rundell, Esq.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 12th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

In 1862 one of the evening meetings of this Institution was given up to papers on the magnetism of iron ships. The first and second papers were by my valued friends and colleagues in the discussion of the compass question, the late Mr. Archibald Smith, M.A., F.R.S., and the late Sir Frederick J. Evans, R.N., F.R.S., who was then in charge of the Compass Department of the Royal Navy. The third paper, written by myself, was devoted to compass compensation and outfit. At that time the mechanical compensation of the compass on board iron vessels was much deprecated at the Admiralty, but changing circumstances, and more especially the use of armour plating, soon did away with much of the prejudice which then existed against this mode of compensation, so that in the course of a few years it became as general in the Royal Navy as it had long been in the Mercantile Marine.

In the third report of the Liverpool Compass Committee, printed as a Blue Book in 1861, I have described some examples of the successful introduction of a vertical bar of soft iron at a short distance in front of the steering compass, for the correction of the error which arises from change of magnetic latitude when the steering compass is situated near the stern of the vessel. At that time this position for the steering compass was nearly universal in merchant vessels, and the object of my paper of 1862 was to show to naval architects and shipbuilders that a compensating bar should always be introduced, and form an acknowledged part of the outfit of an iron ship.

A few weeks after the paper was read I had occasion to introduce this iron bar compensation into the Cunard Steamer *Scotia*, then the largest vessel in the Cunard fleet, and also into two or three other large steamers. The case of the *Scotia* was a very remarkable one from a magnetic point of view, and at this distance of time I shall not

be chargeable with breach of confidence if I relate some of the details. Had not the case been out of the common run, possibly my assistance would not have been requested.

At the present time, when the theory of the magnetism of iron ships is so generally understood by naval architects, it will only be necessary for me to refer in a very brief way to the effect of the earth's induction on soft iron. Magnetic induction is most conveniently illustrated by observing its effect on a piece of rod iron of about 20 inches in length and half an inch in diameter. This rod becomes most magnetic when held in the plane of the magnetic meridian, and at an inclination or dip, here at this place, of about 67°, but it does not become magnetic in the direction of its length when held in any position in a plane at right angles to the direction of the dip. In positions lying between this plane of no induction and the direction of the dip, the amount of magnetic induction in the rod will vary as the sine of the angle which it makes with the plane of no induction. Thus, if the transient induced magnetism of the iron rod, when held in the direction of the dip, be called 1, its induced magnetism, when it is held vertically, will be represented by ·921, the natural sine of 67°. When the bar is held horizontally, and towards the magnetic north, its inductive magnetism will be represented by ·391, the natural cosine of the same angle.

Assuming perfect induction in the bar, and that the induced magnetism in bars of similar diameter would vary in proportion with the length of the bar, a horizontal bar in this locality would have to be $\frac{921}{391} = 2{\cdot}356$ times the length of the vertical bar to be equally magnetic from the earth's induction.

Just now I wish you to consider the magnetic condition of a bar or rod of soft iron when placed at an angle of 23° above the horizon, and then made to rotate round a vertical axis. Let the diagram Fig. 1 be supposed to lie in the plane of the magnetic meridian, and let S N represent the bar at the prescribed angle. The line D N will represent the line of dip at 67°, and the line N P the plane of no induction, at right angles

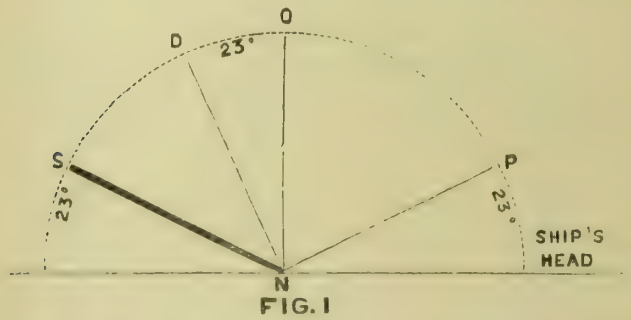


FIG. 1

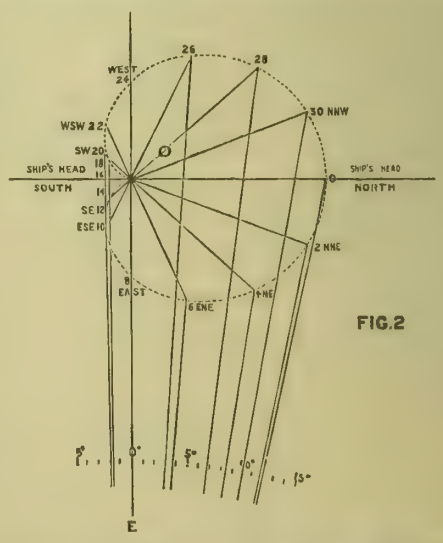


FIG. 2

to the dip and inclined at an angle of 23° to the horizon. Rotate the bar S N

through 180° round the vertical axis O N, and it will then lie in the plane of no magnetic induction. The first position of the bar is that in which its induced magnetism would be greatest; in the latter its induced magnetism will disappear altogether. In all intermediate positions during rotation its induced magnetism will vary as the $\cos^2$ of half the horizontal angle which the direction of the bar makes with the magnetic meridian; or, supposing the bar to be on board ship, and the lower end directed towards the bow, its magnetic value will vary as $\cos.^2$ of half the azimuth of the ship's head. If a compass were placed on the left, or port side, of the top of the bar S, and retained in the same place while the ship was swung round towards the different points of the compass, deviations, chiefly plus or easterly, of a peculiar character would be seen. If the compass be placed on the right or starboard side of the top of the bar, the deviations would be of the same form, but chiefly minus or westerly deviations.

As deviations of this form are not mentioned, so far as I am aware, either in the Admiralty Manual or in any other work relating to the compass, I must ask permission to describe them somewhat in detail, and I shall be able to do so by a diagram and a mechanical construction, which will be easily understood.

Let the magnetic induction of the iron bar in question, when it is directed towards the principal points of the compass, be represented in value and direction by the radial lines in Fig. 2. Let the line O 0 represent its value when the ship's head is towards the north, and let O E be the value and direction of the earth's magnetic force, drawn upon the same scale, and five times the length of O 0. The line E 0, the resultant of the two forces, will indicate the direction taken by the compass needle, and the angle O E in degrees, as read upon the divided portion of a circle, will be the deviation of the compass for that position of ship's head. In the same way, taking the line O 4, draw the resultant E 4, and the angle O E 4 will be the deviation when the ship's head is north-east. The resultants drawn from E to 2, 6, 10, 12, 14, &c., will in like manner show the deviations corresponding with these directions of ship's head. The bar, when ship's head is in the direction marked east and west, produces no deviation, because its attraction is then in the same direction as the earth's force O E. The deviations read off to the right of O E are plus or easterly deviations. Those to the left of the line O E are minus or westerly deviations. The Table I. shows the deviations so read off for the principal points of the compass. For smaller values of the induced magnetism of the bar, as compared with the earth's magnetic force, proportional values may be taken from this table of deviations without sensible error. Fig. 3 represents these deviations graphically.

TABLE I.

Points.	Ship's Head, Correct Magnetic.	Ratio of Magnetic Modulus × ½ cos² of angle, &c.	Compass Deviation.
			° ′
0	N.	1·	11 15
2	N.N.E.	·962	11 0
4	N.E.	·854	8 0
6	E.N.E.	·691	3 35
8	E.	·500	0 0
10	E.S.E.	·309	−1 35
12	S.E.	·147	−1 30
14	S.S.E.	·038	−0 25
16	S.	·0	0 0
18	S.S.W.	·038	−0 25
20	S.W.	·147	−1 10
22	W.S.W.	·309	−1 20
24	W.	·500	0 0
26	W.N.W.	·691	2 35
28	N.W.	·854	6 5
30	N.N.W.	·962	9 15
	Sum of + deviations		+51 45
	Sum of − deviations		− 6 25
	Algebraic sum		45 20
	One-sixteenth =		+ 2 50

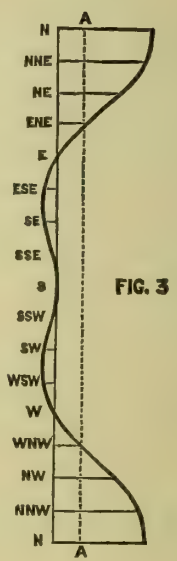


FIG. 3

It may be said that usually we do not find on board ship in proximity to the compass a bar of iron making an angle of 23° with the horizon. This is true, but the same effect may be produced by a bar bent so that while one part is vertical, the other part shall be horizontal, the length of the parts bearing the ratio of the sine to the cosine of this angle. When the ship's head is north the horizontal component will double the magnetic effect of the vertical component, and when the ship's head is south, destroy it altogether. It is admitted that such perfect inductive action as this must not be expected in the iron of a ship. It is more or less checked at each scarph and transverse line of rivets, but on the other hand there is so much greater length in the ship compared with its depth than in the proportions just spoken of, and there is also so much more mass in the keel and bottom of the ship than in the stern-post and other iron at the stern, that we may reasonably expect even a greater change in the horizontal induction than I have supposed, on the ship's head being turned from north to south, and the reverse.

An inclination of the iron bar at the angle of the complement to the magnetic dip has been selected for illustration, because the change in its induction at this angle, and the deviation of the compass which arises from it, is then most easy of explanation. If

the angle of inclination be varied, similar deviations of the compass will be obtained; but these will be mixed up with other deviations, which may now be more readily explained.

(1) When the angle of inclination of the iron bar to the horizon is greater than 23°.—Here there will be added a polar deviation, which will increase with the angle of inclination until it reaches a maximum, when the iron bar is vertical. The deviation, which varies as $\frac{1}{2}\cos^2$ of the azimuth of ship's head, gradually decreases as the angle of inclination increases, and vanishes when the bar reaches the vertical position.

(2) When the bar rotates in the horizontal plane, the compass remaining in the same relative position on the port or left hand side of the after end of the bar.—There will now be no magnetic induction in the bar when ship's head is east or west, as it will then lie in a plane at right angles to the magnetic dip. As the ship's head passes through the northern half of the azimuth circle the deviations will be all plus, and vary as $\cos^2$ of the azimuth. The deviations being due to the attraction towards the bar of the *north* end of the compass needle.

As the ship's head moves through the southern half of the azimuth circle the deviations will again be plus, and vary exactly as in the northern half of the circle, but will now be due to the attraction of the bar for the *south* end of the compass needle.*

Here we obtain a deviation which would produce an apparent index error, the co-efficient + A of the Admiralty manual, but one which evidently could not be cancelled by moving the lubber line of the compass bowl by the amount of this + A to the right.

(3) For inclinations of the bar lying between its horizontal position and 23° above it we shall again have to distinguish between those parts of the azimuth circle in which the deviation is due to attraction of the bar for the *north* and for the *south* end of the compass needle. The azimuth circle will no longer be divided into two equal parts. The part in which the attraction of the north end of the compass-needle obtains will constantly get larger, until at 23° it will, as we have already seen, extend to the whole of the circle, and the attraction of the south end of the needle disappears altogether. As the angle of dip increases from 0° to 23° we obtain deviations involving all expressions for azimuth of ship's head lying between $\cos^2$ and $\frac{1}{2}\cos^2$ on the one side, and from $\cos^2$ to every multiple of $\cos^2$, until this expression vanishes by the attraction of the south end of the needle becoming 0.

The deviation of the compass which I have now described cannot be compensated by a permanent magnet, or by any of the methods commonly in use.

The vertical bar of iron which I have recommended should be two to three inches in diameter, placed parallel to the stern-post and in front of the steering compass, and

* See note at the end of the Appendix.

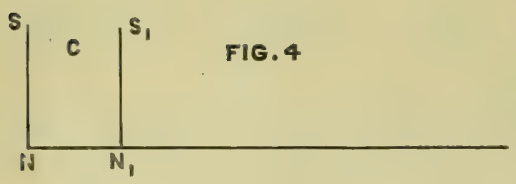


FIG. 4

securely riveted to the iron of the bottom of the vessel. See S_1 N_1, Fig. 4, in which S N represents the stern-post of the vessel. Here it will be subject to changes of induction of the same kind, if not in degree, as the stern-post itself, so that a position for the compass may be found between S and S_1, say at C, in which deviations arising from changes in the horizontal induction will be compensated, as well as those which arise from change in the vertical magnetic induction due to change of magnetic latitude. It has been very successfully applied for this last purpose.

Before I describe the case of the S.S. *Scotia*, there is yet another detail to which I must refer. In obtaining a vessel's magnetic co-efficients A, B, C, D, E for any particular compass, according to the Rules laid down in the Admiralty Manual, it is usual to consider the A and E as normally very small, and to attribute A to index error of some kind, such as the lubber line of the compass being placed rather on one side of ship's head, to error in the shore bearing when the vessel was swung, or some similar and accidental circumstance. The mean value of A is obtained by taking the algebraic sum of all the deviations, and dividing it by the number of the positions on which the deviations were observed. Now if we treat in this way the deviations which we have given in Table I., there would be an apparent + A of 2° 50′, and proceeding by the usual rules there would be found + B of about 3°, a + C of about 3°, a very small + D, and a + E of about the same value as the A. These we can see would be entirely fictitious values in the present case. In practice, if such deviations existed they would usually be mixed up with others and much larger ones, and could not readily be detected. But if in analysing a deviation table by the usual rules an A of one or more degrees be found in conjunction with an E of the same name and amount, or it may be of double amount, there will be grounds for thinking that similar deviations to those which I have described may be mixed up with the table. Until the table has been cleared from these errors, the Rules of the Admiralty Manual will not be strictly applicable, and will give an erroneous result. Whenever the iron around the compass is not symmetrical, or when the vessel while swinging has had a list, deviations of the kind I have described will certainly be found if the table be carefully investigated.

If I have succeeded in explaining these preliminaries, there will be no difficulty in making the case of the steamer *Scotia* easily understood. In the position in which the vessel was lying when I first inspected her steering compasses, the ship's magnetism seemed to be stronger than that of the earth. The cards, when moved, had no directive power to settle in any fixed direction, so that no consistent readings could be obtained until magnets had been fixed on the deck to counteract some of the strong magnetism at the stern of the ship. After the fore and aft and transverse magnetism had been

partially corrected, the vessel was swung on April 12, 1862, and the following co-efficients were obtained in the usual manner from the deviations observed upon the eight principal points :—

	A	B	C	D	E
Port-steering Compass	− 4° 0′	+ 3° 30′	− 19° 0′	+ 3° 8′	− 6° 56′
Starboard-steering Compass ...	+ 3 30	− 2 38	+ 12 4	− 4 22	+ 9 8

These were most extraordinary values for A, and being opposite in kind in the two compasses, could not be attributed to the ordinary causes. The values for E were yet more uncommon.

Had the power been given to me the wheel-house should have been taken down and the compasses removed bodily further away from the stern of the vessel, but this was not possible under the circumstances. It was of no use to abuse the shipbuilder for putting the wheel-house in such a bad place, or for going to the great expense of putting a brass spindle and fittings to the huge capstan, which stood immediately in front and between the wheel and deck-houses. An iron spindle and capstan would have assisted to correct these large compass errors.

An iron bar was placed close to the front of the wheel-house, its lower end being firmly secured to the bottom of the vessel. The large co-efficients A were corrected by turning the needles of the port compass card 4° to the right of their usual position, and those of the starboard compass were turned 3½° to the left. The cards were conspicuously marked—"This card to be used only for the port-steering compass," the other—"This card to be used only for the starboard-steering compass." This course was considered to be preferable to altering the lubber lines of the compass bowls. The cast-iron quadrantal correctors were placed obliquely so as to correct part of the E as well as the D, but were not nearly strong enough to correct the whole of these errors. This mode of correcting the D and E errors by the same pieces of cast-iron had previously been successfully used on board the S.S. *Kedar*. With such large deviations, and with the correctors placed so close to the compasses, I considered it necessary to use needles of only half the usual length, and to place the poles of the two needles as nearly as possible 60° apart on each card. The needles were about 3½ inches in length. Much has been done of late years by Sir William Thomson to bring short needles and lighter cards into use, but I believe this was the first time that short needles were introduced specially to obtain more perfect compensation.

When these necessary arrangements had been completed the vessel was again swung, on the 16th of April. Again, on the 30th April, before the vessel sailed, the deviations of the compasses were observed for about twenty-two out of the thirty-two points of the compass. The co-efficients for the two steering compasses, as obtained from the eight principal points, were :

April 16th, 1862.	A	B	C	D	E
Port steering compass	− 0° 9′	+ 1° 15′	+ 1° 26′	+ 2° 31′	− 5° 23′
Starboard steering compass ...	− 0 45	− 0 25	+ 2 13	+ 0 28	+ 4 32
April 30th.					
Port steering compass	− 0 15	− 0 48	− 1 3	+ 1 30	− 4 8
Starboard steering compass ...	+ 1 58	− 0 2	+ 1 53	− 0 23	+ 4 34

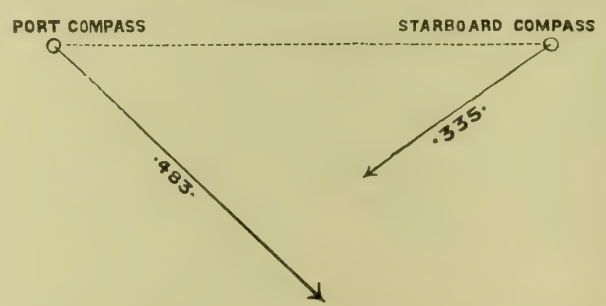
It was an advantage for the E in the two compasses to be of about the same value, one plus and the other minus, as the mean of the two errors gave very nearly the correct magnetic course.

In re-examining the case, I now see that it was a mistake to apply to these deviations the Rules of the Admiralty Manual, and that these co-efficients are all spurious ones. I hope to be allowed to add a brief appendix to this paper, to show an analysis which will better represent the deviations of the steering compasses of the *Scotia* which remained uncompensated.

It should be stated that the vessel was well supplied with other compasses, there being a standard, a tripod compass, a bridge compass, and two other fixed compasses. The maximum error of the tripod compass, uncompensated, was less than 12°.

Neither in the *Scotia* nor in the *Kedar* was opportunity afforded for ascertaining the total amount and direction of the ship's magnetic force at the station of the steering compasses. In the *Persia*, where there was much less error, the values were—port compass, ·483 of earth's horizontal force at 223° starboard angle; starboard compass, ·335 at 323° starboard angle. This is shown graphically in relative amount, and direction in Fig. 5.

FIG. 5

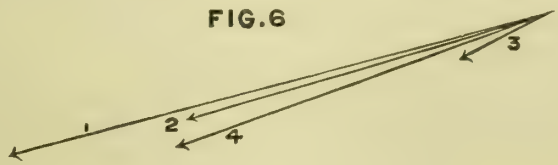


Here it may be stated that the co-efficients for the steering compasses of the steamers *Scotia*, *Kedar*, and *Persia* resemble those obtained by the rotation of the bar at an inclination to the horizon at an angle of 23°. In each case the A and E are large, and of the same name for the same side of each vessel. We are enabled, therefore, to indicate with some confidence the direction in which the disturbing influence is to be found, namely, on the port side of the port compass, and on the starboard side of the

starboard compass; in other words, in the quarters of the vessels, precisely those parts which partake most of the oblique direction of the experimental bar. We now see also that a more complete compensation of the steering compasses of the *Scotia* would have been obtained if the vertical iron bar had been brought nearer to these compasses.

To illustrate the change in the magnetism of an iron ship, which may occur from a great change of magnetic latitude, no better example can, perhaps, be given than the case of the *Royal Charter*. This is exhibited graphically in Fig. 6. The compass in this case was not a steering compass, but was one fixed in a specially favourable position, considerably raised above the deck, and free from the disturbing influences of near masses of iron. Fig. 6 shows the direction and value, in terms of the earth's horizontal force at Liverpool, of the ship's magnetism at the station of this compass at four periods between January and October of the same year, 1856.

FIG.6



(1) At Liverpool in January.

(2) At Melbourne in May.

(3) On her return to Liverpool, and before going into dock in August, and

(4) Before going to sea on her second voyage in October.

Place.	Date.	Relative Force.	Starboard Angle.
1. Liverpool... ...	January	·344	258°
2. Melbourne ...	May...	·252	257°
3. Liverpool... ...	August	·062	238°
4. Liverpool... ...	October	·258	248° 30′

The third swinging, which shows such an important and unexpected change in the ship's magnetism, was obtained by Dr. Scoresby and myself by pure accident: (1) through my having gone to meet the *Royal Charter* in a tug boat when she was reported off Liverpool, and (2) by making use of the compass bearings of Vauxhall chimney, Liverpool, which had been painted on the dock walls during Dr. Scoresby's absence. It will be seen that, after the vessel had remained a few weeks in Liverpool, the magnetic force was quadrupled, and that the ship regained three-fourths of the magnetism which she had previous to her first voyage. But for the coincidence of

these accidental circumstances, the great change which took place on the homeward voyage would not have been recorded or even suspected.

In the important course of lectures on "Magnetical Errors, Compensations, and Corrections, with special reference to Iron Ships and their Compasses," which was given in March, 1865, to the Royal School of Naval Architecture and Engineering, at the South Kensington Museum, the lecturer, Sir George Biddell Airy, was so good as to give my name to the fixed vertical bar which I have just described in this paper. At page 21 of the syllabus, speaking of the order of the operation for correcting a ship's compass, he says: "First, for a compass near the stern, Rundell's vertical bar ought to be used." At pages 18 and 19 he states that when I proposed this compensation it was apparently without knowing that Captain Flinders had also suggested the use of a vertical bar in the early part of this century.

This was quite correct. But I would point out that no question has ever arisen as to the priority of the suggestion of a vertical bar by Captain Flinders, and I have always been pleased to hear the detached vertical bar, now sometimes used for compass correction, called a Flinders' bar. Our objects were different. His bar was to be placed abaft the compass, and was intended for the correction of changes in the iron of wooden-built ships, arising from change of vertical induction on a change of magnetic latitude. Sea-going iron vessels were not then in use. My object, in addition to this, was to cure what had not then received a name—sub-permanent magnetism; and also, as I have described in the course of this paper, errors due to the horizontal induction of vessels built of iron—errors which require that the compensating bar should be of considerable length, and be really made a part of the structure of the vessel.

The name of Sir George Airy, the father of the mechanical compensation of the compass in iron vessels, having just been mentioned, it may not be inappropriate to remind you that the present year is the fiftieth since Sir George Airy presented to the Royal Society his celebrated paper on this subject with the account of his experiments on the *Rainbow* and *Ironsides*. Fifty years is a long period in one man's history, and Sir George Airy may well be proud in looking back over this period to see how complete has been the success of his compass investigation. His mode of compensation has been adopted by all the civilised world. Sir William Thomson, one of the latest and perhaps the most successful of modern compass adjusters, when he exhibited his apparatus in 1878 before a distinguished meeting in London, remarked that within the last ten years the application of Sir George Airy's methods had "become universal, not only in the Merchant Service, but in the Navies of this and other countries," and added, "The compass and the binnacles before you are designed to thoroughly carry out in practical navigation the Astronomer Royal's principles."

In conclusion, the moral of my remarks is not a new one. However perfect the

compensation of a ship's compass may be at any given moment, in any given place, it must be remembered that unexpected changes in a ship's magnetism are not only possible, but are also probable. A ship's magnetism is not a fixed, but an ever fluctuating quantity. The more complete and perfect the compensation the less the change and the liability to change may be, but the captain of an iron vessel must always be on the watch for compass errors, and can never dispense with regular and constant reference to the known azimuths and amplitudes of the heavenly bodies.

APPENDIX.

STEAMER "SCOTIA."—APRIL 12, 1862.

1	2		3		4		5		6		7		8	
Points of the Compass.	Port Steering Compass.						Starboard Steering Compass.						Mean of Columns 2 & 5	
	Observed Deviation.		Calculated Deviation.		Difference of Columns 2 & 3		Observed Deviation.		Calculated Deviation.		Difference of Columns 5 & 6.			
	°	′	°	′	°	′	°	′	°	′	°	′	°	′
N.	−22	15	−20	27	−1	48	28	15	24	55	3	20	3	0
N.N.E.	−15	45	−15	22	−0	23	22	0	21	7	0	53	3	8
N.E.	−4	30	−7	52	3	22	11	0	11	55	−0	55	3	15
E.N.E.	4	0	1	50	2	10	1	30	−1	27	2	57	2	45
E.	6	45	6	15	0	30	−6	30	−9	40	3	10	0	8
E.S.E.	4	0	5	18	−1	18	−9	0	−10	37	1	37	−2	30
S.E.	1	0	1	55	−0	55	−7	0	−5	40	−1	20	−3	0
S.S.E.	0	0	−0	33	−0	33	−2	45	−1	8	−1	37	−1	23
S.	0	30	−0	30	1	0	0	0	−1	10	1	10	0	15
S.S.W.	2	0	1	38	0	22	1	30	−0	43	2	13	1	45
S.W.	2	45	2	45	0	0	1	30	−4	20	5	50	2	8
W.S.W.	1	45	1	8	0	37	0	30	−6	27	5	57	0	38
W.	1	15	−3	15	2	0	−2	0	−4	45	2	45	−1	38
W.N.W.	6	0	−9	0	3	0	1	45	1	13	0	32	−2	8
N.W.	15	15	−14	45	−0	30	12	0	10	20	1	40	−1	38
N.N.W.	22	0	−19	17	−2	43	24	0	19	42	4	18	1	0

In this table the deviations, columns 2 and 5, were obtained at the date named by drawing a fair curve through the observations then made and projected upon paper. No attempt has been made at improvement or correction. The deviations given in columns 3 and 6 are from calculation. The differences between the observed and calculated deviations are given in columns 4 and 7. Column 8

gives the means of the observed deviations, and shows the error which would have arisen if the mean direction of the two compasses had been taken to indicate the correct magnetic course.

A little further acquaintance with the peculiar deviations treated of in this paper would, no doubt, enable one to make a much nearer approximation to the observed deviations.

One special peculiarity in the deviations produced by the inclined iron bar occurs when the sine of its angle of inclination corresponds with $\frac{1}{2}$ sin 23°. It will then lie in the plane of no magnetic induction when ship's head is S.E. and S.W. Between S.E. and S.W. by way of South the deviation will be of the same name as the deviations from W. to E. by way of North, so that these deviations, through twenty-four points of the compass, will unite to give a large co-efficient A and a large co-efficient E, if they were treated according to the Rules of the Admiralty Manual; but, as has been already explained, these co-efficients would be spurious ones. Between E. and S.E., and between S.W. and W., the deviations would be very minute, and of the opposite name to those at South and North.

Note.—Since the foregoing paper was read a re-examination of the case of the *Scotia*, and some much larger examples of abnormal compass deviations have shown me that a general equation may be given which will represent the deviations, due to magnetic induction in an iron bar for all angles of inclination, as well as for all magnetic latitudes, and that this general equation will avoid the use of the unusual expressions for the azimuth of ship's head which I have given in the text.

Using Fig. 1, let Δ = the angle of dip.

$V = D N \sin \Delta$.

$H = D N \cos \Delta$.

δ = deviation of the compass.

θ = angle of inclination of the bar to the horizon.

ζ = the azimuth of ship's head commencing at north.

ς = starboard angle, or horizontal direction of the bar in relation to the fore-and-aft line of the ship.

$$\text{then } \delta = V \sin\theta \times \cos(\zeta + \varsigma) + H \cos\theta \times \cos^2(\zeta + \varsigma),$$
$$= \{V \sin\theta + H \cos\theta \times \cos(\zeta + \varsigma)\} \cos(\zeta + \varsigma).$$

W. W. R.

DISCUSSION.

Admiral A. F. R. de Horsey (Associate): My Lord, I thank you very much for calling on me to speak on this most interesting paper, but I have no remarks to make, except that I desire to accentuate the moral inculcated on ship masters and owners by the last paragraph of Mr. Rundell's paper, viz., that, however perfect may be the compensation of a ship's compass, these appliances—valuable as they are—can never relieve captains of ships from the necessity of frequent observations of the azimuths and amplitudes of heavenly bodies, as a check upon possible errors and unsuspected changes of magnetism.

Rear-Admiral P. H. Colomb (Associate): I am afraid I am only speaking to fill up a gap, because I am not competent to follow up the theoretical part of the paper; but there are one or two remarks made at its conclusion which have practical value with which I might possibly deal. For the purpose of

certainty in navigation, I think that it is better to rely upon continually correcting your compass than to rely upon deviation tables taken out at possibly uncertain periods, and sometimes relied upon when the conditions have altered. That reasoning has from the very first led me to lay great stress on Sir William Thomson's compass. The fact that you have a compass which you do not propose to trust, and are constantly referring, as the author of the paper has said, to correct observations of the heavenly bodies, seems to me to be the safest method of dealing with the compass, and I think that the paper in drawing strong attention to the fact that no deviation is at all permanent, is a matter which will be useful to all those who go down to the sea in ships.

Mr. E. Blackmore (Associate): I should like, as an old officer of the Mercantile Marine, to endorse what Admiral Colomb and Admiral de Horsey have said, that "proper adjustment should be made at the outset." We all know, however, the variations that take place, and every one of us who has had experience of taking ships away from Great Britain, going south, and navigating them for years in Eastern waters, as I have, can only come to the conclusion that, after they have passed the latitude of 10° south, any compass deviations which may have been given at home are utterly useless, and after that the navigator of the ship must depend entirely on his observations for his own corrections, and make use of his compass according to the rules supplied to him for taking deviations from day to day. On two occasions I have taken ships away under these conditions, and in one case for four years after pulling up my magnets, I navigated the ship all through the Eastern waters, all round the coast of India, all up the China waters, to the Gulf of Pechili, and back again, without any compass adjustments whatever, dependent entirely upon my observations from day to day. I can only impress upon navigators in general that they must not depend on the adjustment given them at home, but they must, from the very outset, trust to observations taken from time to time, and in various latitudes, for the correction of their compasses, and the proper navigation of their vessels.

Captain G. Beall (Visitor): My Lord, there is just one remark I should like to make in respect to the following observation in the paper just read. Mr. Rundell observes:—"It may be said that usually we do not find on board ship in proximity to the compass a bar of iron making an angle of 23° with the horizon." As explained, and shown in the diagram, he, of course, refers to iron at an angle of 23° with the horizon end on, so to speak, to the compass. There is, however, another position on board ship in which we may sometimes have athwartship iron at this angle to which I might perhaps be allowed to refer. Supposing, for example, the vessel's head is N.E., and she heels over to port, say 23°, in that case the lower ends of the transverse or athwartship iron—beams for example—would be (roughly speaking, of course) pointing in a direction approaching towards the earth's line of force, and consequently would acquire much more magnetic force than when the vessel heels over to starboard, for then the beams would be in a position more at right angles to the earth's line of force. This obviously accounts, to a considerable extent—though I have not seen it specially referred to in works on the subject—for the difference generally found in the amount of the heeling error as the ship heels over to port, and to starboard; and I should like to ask Captain Creak what his experiences are in the matter. I may say that I have tested this on an instrument of mine called the "Deviascope." Using two athwartship bars (representing beams) I found, with ship's head at N.E., about 6° of heeling error when heeling over to port, but when heeling over to starboard only 4°—a very considerable amount of difference. I do not know, my Lord, that I have anything further to add, except that I am sure everyone of us who takes any interest in compass matters must feel pleased to see Mr. Rundell's name still to the fore. He has been connected with this subject for very

many years, and anyone who has occasion to refer to the Reports of the Liverpool Compass Committee cannot but be struck with the great amount of labour which he has expended on these matters.

Staff-Commander Creak, R.N., F.R.S. (Visitor) : My Lord, I do not wish to detain the meeting for long, but a few remarks have been made which I should like to reply to, having had some experience in these matters for some years past. I entirely endorse what Admiral de Horsey has said, and I think his remarks are among the most valuable that have been made to-night. I am very sorry to differ from Admiral Colomb, but I cannot agree that one should be continually correcting the standard compass, because I think if you did you would lose all record of the changes in a ship, and the time would come when observations were unattainable, and a doubtful course would have to be steered, instead of one practically certain. Take the *Inflexible*, for instance, and suppose that she is steered an easterly course for three or four days, and that she turned to proceed up through the Archipelago, are you then to correct her deviation for the amount she should have altered whilst running on the previous course ? By the time she got up to Constantinople that amount would probably be all dissipated, and in the meantime you would require a change of the magnets every few hours. There are a number of instances which I could give you where ships have been running for a time on a course, and if you constantly corrected the compass for the consequent errors you would have no record for future guidance. I do not know as much about the mercantile marine as my own service, but I have gone over about one hundred vessels of all classes during the last few years, and my experience is that there was hardly a case in which the captain of a mercantile steamer ever altered his magnets, but trusted entirely to his observation, which is the only sound practice, because he gets a record of his compass and keeps it in his compass journal, and he knows at any part of the world, or at any future time, if observations are not to be had, what the error of his compass is likely to be. The compass obeys temporary changes in the ship, which follow well-known laws, therefore I think it is an imprudent thing to be constantly altering the magnets of your standard compass. By the standard compass I mean the compass by which the ship is navigated. In the Royal Navy we are not so much troubled about changing deviation. I can give instances of two ships which have lately gone abroad ; one the *Impérieuse*—the change in deviation of her standard compass was practically nil, and her deviation table was for the Cape. Now, I know no more convenient range of magnetic latitude when you wish to find out the changing part of a ship's magnetism than from England to the Cape, as you go from 67° North Dip to 56° South Dip, and the horizontal forces are about the same. The other ship is the *Orlando*, with little or no change between England and Australia. I am sorry to dissent from so talented an officer as Admiral Colomb, but having studied the subject somewhat fully, I am bound to say what I think in opposition to a practice which I consider to be injurious to the safety of our ships. It is with me a matter of experience and not a question of opinion, and my experience is a long one, for I have devoted twenty-one years to questions connected with compasses on board iron ships. In regard to Mr. Rundell's paper I should like to make a few remarks. I agree with what Captain Beall said when he made a remark about the heeling error. We inclined the *Orlando* last year, and tried the compasses in five different places—on the top of the conning tower, inside the conning tower, and various places below ; and in only two instances did the calculated deviations agree closely with the observed. In one of the worst places we got $2\frac{3}{4}^{\circ}$ error for every degree of heel. The theoretical heeling error was $3\frac{1}{2}^{\circ}$, but still we had its value sufficiently in hand for practical purposes. In regard to Mr. Rundell's paper, I do not hold myself responsible in any respect for what appears in it. It is entirely his own. It was given to me at one o'clock to-day, and I have not as yet come to any definite conclusion about it ; but speaking from what I have already seen, the paper really refers principally to what are called in the Admiralty notation, the co-efficients A and E. He is not satisfied with their

treatment in the Admiralty Manual. He then goes into the question of the deviations caused by an inclined bar and the necessary correction. Considering the extraordinary places we have to put our compasses in on board some of our men-of-war, I cannot yet see how we can trace in any particular position the force or direction of any particular mass of iron causing deviation in the ship. We have to consider as a whole the deviation we get from the horizontal forces, to analyse them, and to arrive at certain conclusions, leaving the vertical forces for separate treatment. Mr. Rundell furnishes me to-day with a diagram which any gentleman can see, in which he says that he got better results from his way of treating the compass deviations than we at the Admiralty can get. My colleague has worked it out for me, and the results are these: As a rule the deviations computed on the Admiralty system agree better with the observed than Mr. Rundell's do. The mean error of the Admiralty calculated deviations is 1° 14′ from the observed, and Mr. Rundell's 1° 24′. I think that the results which we obtained are the more correct, but that is a matter to be thought out. I could not quite get to the bottom of his paper in the short time at my disposal, but I am so fond of my old love that I do not want to change to a new one before I am off with the old. I will still stick to the Admiralty Manual until I get something that I know is better. There is only one thing to be said of the application of our formulæ. I think that a great many of the troubles to be met with in this respect arise from our having rather abused Archibald Smith's formulæ than used them. His formulæ were based on certain considerations; one was that the needle should be absolutely a point compared to the surrounding iron, and that the surrounding iron should be tolerably symmetrical. He did not expect they were going to put our compasses within a few inches of eight-inch armour plating. At present I am satisfied, until I have seen more of Mr. Rundell's paper, with what I have got. But knowing Mr. Rundell's ability on the subject, his long service, and long experience in the matter, I would treat all he says with the greatest possible respect. I shall look into his paper diligently, and see if I can find any hole in our Admiralty armour, and if so, I shall only be too glad for one to repair it.

The President: I am sure we all feel very much indebted, not only to Mr. Rundell, but to the reader of this paper, for I take it that he has convinced you that Mr. Rundell, when he trusted him to read his paper, placed it in the hands of one of the most competent critics of the subject that could be found. You will allow me to render to Captain Creak, who will convey them to Mr. Rundell, your thanks for the paper, and for the admirable and most practical and experienced criticisms which the paper and the remarks which have been made upon it have received at the hands of Captain Creak.

ON BOAT LOWERING AND DISENGAGING.

By Edward J. Hill, Associate.

[Read at the Thirtieth Session of the Institution of Naval Architects, April 12th, 1889; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

On the 5th April, 1873, I had the honour of reading a paper before this Institution on the subject of "Lowering and Disengaging Ships' Boats at Sea," and explained an entirely novel kind of detaching hook. About this time public attention had been drawn to the subject by the sad accident to the boats of H.M.S. *Ariadne*, then in the Mediterranean, and the loss of the emigrant ship *Northfleet* off Dungeness. Three other papers were read at the same meeting by F. J. Sweeting, Lieut. Stephanoff, and C. G. Gumpel, resulting in a discussion, in which the late President, the Right Hon. Lord Hampton, Admirals Sir John Hay, Selwyn, and Colomb, and Sir Frederick J. Bramwell took part, who at that time expressed a favourable opinion of my hook, which opinion has been fully borne out by the number of boats fitted with the invention, amounting to over 8,000.

Since then I have given a very considerable portion of time to this subject. The result has been that I have not only much altered the original hook, but invented other plans for getting over little difficulties that at different times presented themselves. Before describing the last effort made in this direction, I will endeavour, with your permission, to make a few remarks upon the history of the whole question.

From the earliest date in which a small boat or raft was carried by a larger one for general convenience and safety, we find the only means of launching was by bodily hoisting and sliding overboard. When too heavy for this a block or tackle attached to one of the masts or spars was used. Ships were afterwards built having what are termed davits and falls. At first fixed wooden uprights at the side of the ship, then wooden uprights moving upon hinges and pivots called topping davits, then of curved iron fixed in sockets but allowed to turn round, and lately, though but little used, a plan for working a curved iron davit upon a hinge or pivot in a similar manner to the old wooden topping davit. All these plans worked in conjunction with falls and blocks,

the number of sheaves varying according to the weight of the object to be lowered, the lower block having a fixed hook, which hooked into an eye or ring attached to the boat or raft. This old and primitive plan, which has been in use some hundreds of years, seems even now to be the most general method used, in what are known as most beautifully designed and perfectly built modern ships.

From the records in the Patent Office, and a careful study of the inventions on the subject, I find that the first recorded invention for an "Improvement for lowering and disengaging boats" is that of Lieut. Cook, R.N., dated April 24, 1830. This invention consists of a pivoted hook, the point being held by a catch, which, when removed, allows the curved part of the hook to open and slip off the ring.

The next invention was that of Shore, who, later on in the same year, designed a modified and simplified form of Cook's hook. A model of this is exhibited at the Royal United Service Institution.

Nothing further appears till 1852, when Stirling Lacon, Roberts, and Dewey, each patented an invention. From that time to the present the following table will show the number of inventions, and will be interesting as pointing out the fluctuating manner in which the patents for improvements connected with boats, davits, and apparatus for lowering have been applied for:—

1830 ... 2	1859 ... 8	1867 ... 5	1875 ... 11	1883 ... 12
1852 ... 3	1860 ... 3	1868 ... 2	1876 ... 15	1884 ... 32
1853 ... 7	1861 ... 2	1869 ... 1	1877 ... 10	1885 ... 14
1854 ... 1	1862 ... 1	1870 ... 8	1878 ... 9	1886 ... 21
1855 ... 1	1863 ... 4	1871 ... 6	1879 ... 9	1887 ... 26
1856 ... 5	1864 ... 2	1872 ... 14	1880 ... 7	
1857 ... 5	1865 ... 3	1873 ... 20	1881 ... 9	
1858 ... 7	1866 ... 8	1874 ... 9	1882 ... 11	

The great difference that appears in the number taken out each year may be accounted for by public attention being from time to time drawn to this subject by numerous and sad disasters at sea, followed by Life Saving Exhibitions, one of the first of which took place in April, 1873, at the London Tavern, for the *Northfleet* Relief Fund, when no less than twenty-four different inventions were exhibited. From that time the increase has been very great. Thus we see that between 1830 and the end of 1887 no less than 313 plans have been provisionally protected or patented, and that during the last thirty-six years 311 inventions or designs have been made. A few of these have been simply for altered form of davits. The remainder are for lowering and disengaging, and should be divided as follows:—

Division 1.—Methods of lowering by unreeving pennants placed round drums and rollers.
,, 2.—Slip hooks.
,, 3.—Tumbler or weighted hooks.
,, 4.—Ball and socket catches or slips worked by rods and levers.
,, 5.—Cradles.
,, 6.—Improvements of common hook and ring with increased safety.

It seems strange that, although so many plans have been designed for boat lowering, the old and original hook and ring should be generally used at the present time. It will, however, be found, when the inventions are carefully examined, that they are nearly all more or less simple alterations of one or other of a few plans that have, in times gone by, been tried and found wanting.

For instance, under Division 1, Clifford's seems to be the only one that ever came into extensive use.

Under Division 2.—Kynaston's, Robinson's, and Digby Murray's, all of them working in a similar way to Kynaston's.

Division 3.—Tumbler or weighted hooks have been found so unreliable that no one system is at present in much use, although numerous patents have been taken out for them, nearly all being a slight modification of Shore's hook of 1830.

Division 4 comprises the largest number of patents, the principles of which consist of different methods of slips and catches attached to the falls, but all dependent upon the free action of rods, chains, and levers fixed in the boat. Only three have been used to any extent, namely, Wood and Rogers's, 1859; Douglas's, 1876; and Sample and Ward's, 1879.

Division 5 includes the system of holding a boat in a cradle or crutch, which cradle or crutch is sufficiently lowered until the boat floats off it. There are only a few plans, but none have been subjected to an exhaustive trial.

Under Division 6 only two plans seem to have been used, namely, Lambert's improved fixed and moused hook, 1859; and Hill and Clark's, 1870-71-72-79. Robinson in 1881 claimed a design like Lambert's 1859 hook, which has, however, not been used. After very exhaustive trials, Hill and Clark's plans have been fitted to over 8,000 boats in Her Majesty's Navy and the Mercantile Marine.

Thus it will be seen that the only plans which have been used to any extent may be counted upon the fingers, and consist of Clifford's, Kynaston's, Robinson's, Murray's, Wood and Rogers's, Sample and Ward's, and Hill and Clark's.

In 1856 Clifford's invention was officially tried and adopted by the Naval authori-

ties and Board of Trade Emigration Officers, in one or two boats of a ship, and at the time was certainly the most admirable system then known, although of late years, through the difficulty found in keeping the working parts in order, the use of it has been almost entirely discontinued, and other systems have taken its place.

Captain Kynaston, in 1857, invented a slip hook, worked by the coxswain, which, after trial by the Admiralty, was approved for use in two quarter boats of H.M. ships, and about 1869 an official order was issued to the effect that this plan was to be supplied to two boats of every ship in H.M. Navy; but the evidence collected by the Committee appointed by the Lords Commissioners of the Admiralty, to "Inquire into the supply of lifeboats to the Navy, 1872, and the best mode of lowering boats and saving life at sea," tended to show that the power given by this system to the coxswain of the boat, to disengage at any height from the water, caused a great number of accidents, and it was decided not to continue the forced use of this plan, but to leave it to the option of the officers in command to apply for it, since which time but few ships have been supplied with a slip, and these have been of a modified form of Kynaston's hook, designed by Mark Robinson.

Digby Murray's and Wood and Rogers's systems are only in use in the ships belonging to the White Star and Pacific S.S. Companies respectively.

Sample and Ward's patent, dated 1879, is a similar plan in principle to those patented by Leeman, 1875, and Shepherd, 1877, and consists of an arrangement of rods, cranks, levers, and weights placed out of sight below the thwarts, working in connection with two very old and well-known slip hooks, patented by Cook in 1830. The gear, when properly made and fitted, ensures that a boat suspended from the falls cannot be unhooked unless it is entirely waterborne, and all strain taken off the tackles, when the weight falls, drawing with it the rods which project above the nip of the slip hooks, and allows the tackles to be freed. Shepherd's and Leeman's work in a similar way to Sample and Ward's, but have less movable parts to depend upon.

The old plan of Hill and Clark consists of two solid hooks of simple construction, which are fastened in the boat, one at each end, above the thwarts, having no working parts out of sight; a ring, link, or shackle made to fit the hooks is fastened to the blocks of each fall, which, when attached to the hooks, and the boat suspended out of the water, cannot possibly be disengaged; but when the boat is waterborne and the falls slackened, the rings or shackles fall clear of the hooks, and the boat is free from the tackles, the hooks from their peculiar construction rendering it impossible for the rings to accidentally catch again. A wire fore-and-aft line connecting the two rings prevents one end of the boat becoming disengaged before the other, so that the boat is perfectly safe until entirely waterborne. This plan has been used by the English and foreign navies, and is now adopted by most of the large steamship companies. See Figs. 1, 2, 3, Plate XXXIX.

Having thus mentioned a few of the systems to any extent in use, I will now explain the working of the plans invented by myself, and patented in conjunction with Mr. Latimer Clark, Memb. Inst. C.E., since the hook above described, which was brought to the notice of the Mercantile Marine in 1873.

From my practical experience of boat lowering, and the numerous trials I have from time to time made, I have tried to remedy the little objections existing in my old plan and other appliances, and in 1879 patented a somewhat simplified form of this hook arrangement which may be described as a hook shaped in the form of a horse's head, the ears of the same throwing the attaching rings out of the vertical line, in the same way as is done by the back part of the old Fig. 6 hook, the chief advantage of this shape being ease in attaching. This system has also been used and much approved. See Figs. 4, 5, 6, Plate XXXIX.

In 1885, I made a further improvement in the rings of the old apparatus of 1872, by which it was impossible for the men to attach them to the hooks in the wrong manner (Figs. 1, 2, 3).

Still further experience since 1879 has enabled me, after numerous difficulties, I trust, to succeed in inventing a novel hook which can be safely applied to every boat of every ship, which, notwithstanding all failures and faults, has less objections than the old common hook.

The new hook is a solid piece in the form of the letter G. Through the thick or back part of this G is a slot to admit of a small traverser having a U-shaped recess at one end which passes into the opening of the G, not only filling up the aperture, but forming a perfect O. The upper part or actual hook of the G is curved round to such an extent that a ring or hook when engaged is safe to an angle of about 45°, and therefore it is impossible, with a fair strain, for the traverser to be moved; but when this strain is taken off, the ring is inclined to fall into the U of the traverser, and, of course, is easily withdrawn. When it is required to prevent the traverser being moved, in the end which projects through the back of the G, a slot is made, in which a small flat-locking key works. A pin or check is fixed on the traverser to control it in its movements. One of these hooks is fixed at each end of the boat, pointing in the same direction, namely, towards the bow. By attaching a piece of wire rope to the two traversers, the hooks are made to work simultaneously, if desired (Figs. 7, 8, 9, Plate XL.).

This plan can be worked in several ways, according to the desire of the officer in charge: either by two men, one at each end of the boat, one man in the bow of the boat, the coxswain of the same in the stern, the officer in charge of the lowering on board the ship (Figs. 10, 11, Plate XL.), automatically (Figs. 12, 13, Plate XL.),

or by the action of the boat rope, or painter, in all of which cases the reliability of the working of the hooks is ensured, and, again, what is of equal importance, it is rendered impossible for the stern of the boat to be hooked until after the bow end has been attached. Should any of the working parts become deranged, or out of order, the plan can always be worked with more safety and certainty than the common hook and ring, as will be seen from the models.

The idea I had in view in inventing this new apparatus was to make a hook, that when the ring is attached to it, the hook becomes a perfect ring, which is instantly welded, so to speak, for security, and that when the ring is withdrawn from the hook, no actual hook exists. This seems a peculiar idea, and a particularly difficult thing to achieve, but I trust I have succeeded in accomplishing it.

In conclusion, it seems strange that in the Navy they have never satisfied themselves upon the merits of any known plan worthy of being generally adopted for all boats of a ship, and although two or three plans are upon the Admiralty list for fitting, by the regulations no commanding officer is permitted to have more than three boats fitted, although his ship may possibly carry as many as ten or twelve. Surely, if a plan is worthy of adoption to two or three boats, it is equally worthy of being fitted to the whole of them, and if it is not advisable to fit the whole, it should not be put in one or two. This also seems to be the rule with the Board of Trade, Passenger and Emigration Instructions, and is, in my opinion, one of a wrong principle, for it cannot be fair either to the officers or sailors of a ship, nor tend to the proper working of any one system, when we find two different plans for lowering boats in use on the same ship, only those of the boat's crew of the specially favoured boats getting any practical experience in the use of the same, and in cases of collision or other mishap, in which all the boats are required, something like uncertainty must exist in the proper routine necessary for getting them all safely and promptly away.

I am glad to say that after some years of contact with shipowners and sailors, they are now beginning to realise the advisability of having all their boats fitted with one uniform plan, and many of our leading steamship companies now have an approved system fitted to the whole of the ships they build, and the Transport Department of the Admiralty take this reasonable view, and in cases where they charter ships of the Mercantile Marine, compel the owners of the same to fit the whole of the boats with some plan approved by their surveyors. Shipowners, shipbuilders, and those who design ships, should inquire into, and select some plan, which in their opinion is worthy of being fitted to all the boats of a ship, and not to some one or two, and this is now the general rule in the Cunard, Union, Royal Mail, British India, Orient, General Steam, Castle Line, Great Eastern Railway, and other companies.

DISCUSSION.

Mr. Mark Robinson (Member): My Lord, as my friend Mr. Hill has referred to my plan in two or three places in his paper, and as the boat-lowering question, at least in the Royal Navy, long since resolved itself into a mere duel between his plan and mine—plans which represent opposite poles of thought about boat lowering—I will venture to take up a few minutes in an attempt to criticise the ingenious modification (I may almost say reversal) of Mr. Hill's system which he has so skilfully put before us. Perhaps I may go a little further, and say that, as a member of this Institution, I may even owe some apology to it, in that, having been for some years engaged, with success, in dealing with this small but somewhat difficult problem, I have omitted to place my experience at the disposal of the Institution. That I have done so recoils on my own head, because while I can only effectually deal with Mr. Hill's plan by comparing it with my own, the latter is almost or quite unknown to most of the members now present. Amongst minor criticisms I would point out that Kynaston's plan and mine should not be placed in Class 2 of Mr. Hill's list —that is, as "slip hooks;" but in Class 3, "tumbler" (or tumbling) hooks. The term "slip hook" is no doubt used loosely, but I take a "slip" to be a hook with a hinged tongue, released by a kind of shackle being slipped off its point. The objections to such a mode of releasing are manifold, and they are fully recognised by those practically acquainted with the subject. Kynaston's plan and mine, in which a complete hook rotates or "tumbles" on a pivot, belong to a different category. I must also demur to Mr. Hill's statement (speaking of the Navy) that "but few ships have been supplied with a slip, and these have been a modified form of Kynaston's hook, designed by" myself. It is a matter of taste, of course, but I call my plan neither a "slip" nor a modification of Kynaston's hook, but as to the number of ships supplied, the statement is wholly misleading. It will be seen presently why I lay stress upon the extent to which my plan has been used in the Navy, and if in what I am going to say there is too frequent reference to my own plan, it is because it stands to me (as it evidently does to the English Navy) as the typical plan of the non-automatic system, just as Mr. Hill's plan (that is, what has hitherto been known as his plan) is beyond question the typical example of the automatic class. Well, in 1881, when my plan began to come into use in the English Navy, Mr. Hill had had matters all his own way there for some years, and had fitted a great many boats. Nevertheless, since 1881, my plan has almost completely driven every other plan out of the Navy, so that the number of boats fitted with any plan other than Robinson's is now exceedingly small. I have had a list handed to me to-day in which it is stated that, excluding harbour ships, &c., there were at a recent date 121 ships, whose boats were fitted with Robinson's plan, and less than a dozen fitted with all other plans put together—several of the latter being known to be ships long in commission which have had no opportunity of changing their gear. I agree with Mr. Hill that it was a curious decision of the Admiralty not to settle for itself which was the best plan, and then adopt it. The Admiralty left certain plans to "fight it out," and then gave commanding officers power to say what plan they would have. Curious as the solution was, at least it had this effect. There never was such a jury of experts empanelled, and after being at it for seven or eight years, they have given an unmistakable verdict, which is practically unanimous, in condemnation of automatic, and in favour of what, for distinction, I call optional gear, where the time for releasing is left to the option of the man in charge. This is why I attach so much importance to the relative numbers of the rival plans in use in the Royal Navy, where boat-lowering gear is so much more frequently used than it is in the merchant service, and this is why I wish to correct Mr. Hill's scarcely accurate reference to the use of my system. No one will congratulate him more heartily

than I do upon the success of his plan outside the Navy, where the same issues have not been raised, because I know that he has deserved success. Now I would ask a few questions relating to his new plan. A wire rope or a lanyard connects the forward and after hooks. After the forward fall is secured, the after one has to be pushed into its place against the pull of the lanyard, which is bound to be tight. If the boat is pitching about there is considerable danger that the fore and aft line may be lurched against, or caught hold of, and it may be difficult on a dark night for the man to push the bolt home at the right moment. Then, in releasing, is it a convenient thing to have to pull the lanyard from forward? Even if the lanyard is taken round a block in the bow and brought aft again, I still cannot think the plan a convenient one.

Mr. W. H. White, F.R.S.(Vice-President): The model shows what you are speaking about.

Mr. Mark Robinson: I see: it is as I supposed. Mr. Hill speaks of this new plan of his a being at pleasure either automatic or non-automatic—what I call optional. But I can hardly believe that it is put forward seriously as an automatic plan. Years ago, in the plan we are all so well accustomed to, Mr. Hill brought forward an invention as perfect as I have ever known an invention to be. He has doubtless improved it a little since then, in details, but broadly it has always appeared to me to be simply perfect *of its kind*. Of course, I dissent from the "kind," for I maintain that not automatic, but optional, disengaging is the right thing. But as an automatic hook I cannot think that this new one is to be compared with its predecessor. It is to act by means of a falling weight, which is a thing Mr. Hill himself condemns, most justly. The weight is shown in one of the diagrams as falling down in a place which is often required to be occupied by an air case. I cannot think that this plan is put forward at all seriously as automatic. If it is not, then Mr. Hill has come round to my way of thinking, because his gear is no longer "automatic gear," but "optional gear." But even accepting it as optional gear, I think it is optional gear with a good deal of the option left out, because, as shown here, the men cannot release until the boat is waterborne. You would want an exceedingly heavy pull to draw the bolts out, with the weight of the boat on the falls. If the hooks be so modified that the bolts *can* be drawn with the weight of the boat on the falls (which implies that in shape they will cease to be hooks altogether), then the bolts will be liable to be drawn *by accident* at any time after the safety locks are removed, or, worse still, *one* may be drawn, and not the other: I refer to the drawing of the after bolt by a man falling against or catching hold of the lanyard. Thus the new plan cannot with safety be made "automatic"; and it is but imperfectly "optional." I hold strongly that the man in charge of the boat should be able to cast off either before or after he reaches the water, as he may prefer. He should have the maximum amount of control over the boat; he has the responsibility, and he should be able to do what he thinks best. His option, in this plan, is much too restricted.

Captain C. Penrose FitzGerald, R.N. (Associate): My Lord, this is a very old battle—the battle of the hooks. I daresay you have heard it before; I have, several times, for the last twenty-five years. We have tried a great many of them; I have had some little experience with them myself, and I think, without being prejudiced in any direction, the verdict one would give is, they are all excellent, with one proviso, and that is, if you know how to work them. I have had Clifford's, Kynaston's, Robinson's, Hill & Clark's, and I think most of the others. I find a very strong family likeness among most of them, and the only difficulty I found was to teach the men how to work them. We have heard now very graphic explanations of the automatic hook, the non-automatic hook, the optional hook, the non-optional hook, the automatic optional and the optional automatic. When we have

got all these into the head of the coxswain of the boat, and also the crew, we shall have arrived at the very satisfactory result that people will all be saved when they tumble overboard. My proposal is that all these boat-lowering gentlemen should club together, and make a joint-stock company; they should agree to agree about some hook—I do not care which it is—form a joint-stock company, with a general boat-lowering automatic or non-automatic hook. Let it be called the "Board margin" in the Navy, or anything you like to call it; select a pattern, and then we could instruct the men how to use it; because now, with all these varieties, the men are sure to get into difficulties. You instruct a man to pull a string on one hook—Mr. Robinson's, let us say—and it is not Robinson's hook, but Hill & Clark's, or it may be somebody else's hook. You tell him to pull a string on the hook, and it is not the one he thought it was, but somebody else's. What is to be done?—everybody in confusion, the boat is upset, and somebody is drowned. I think if it were practicable for them to give up their jealousies, and to club together and have a general and universal hook, it would be satisfactory to the Navy, and I think also to Mr. Martell and the Board of Trade.

Mr. W. H. White, F.R.S.: Captain FitzGerald, I think you mean to make a perfect ring.

Captain C. Penrose FitzGerald, R.N.: Quite so; but not an Admiralty one.

Mr. W. J. Rees (Visitor): My Lord and gentlemen, I have been taken at a very great disadvantage, by being called on to make a few remarks on this occasion, in reference to Mr. Hill's lecture or paper on boat lowering, as I was only made aware that the subject was to be discussed a few minutes before I came to the Hall. Now, considering I have had some thirty-six years at sea, in all classes of ships, and naturally in all weathers, and consequently well acquainted with lowering and hoisting boats, I think I should know something of the subject under discussion. When master rigger at Sheerness I had to superintend the fittings of a number of boats with both Hill & Clark's, Kynaston's, and Clifford's. I believe I was the first practical man that Hill's hook was brought to, to get my opinion as to its merits; and I think I may say that at my suggestion and advice it was made somewhat complete. Some time after this a trial was ordered to be made with Hill's, Clifford's, and Kynaston's (now Robinson's), with the following results, that Clifford's were not suitable, inasmuch as the ships they were supplied to should at all times have the same draught of water, otherwise the pendants would be either too short or too long, as the case may be. Hill's acted very well in smooth water, but in rough weather I consider they were dangerous, as when a sea struck the boat she would naturally disengage the hooks. Now in Robinson's (a modification of Kynaston's) a man in charge has to let go before the boat takes the water. It answers tolerably well in a low freeboard ship—even then I consider them unsafe, for when lowering with Kynaston's or Robinson's from one of high freeboard such as our old line-of-battle ships, a nervous man or a young hand would let go the line when the ship was taking a weather roll (as frequently happens), the result would be serious to both boat and crew. This happened to one of the boats of H.M.S. *Conqueror*, when the boat was smashed and some of the crew drowned. These trials were made in a frigate from the Nore to South Foreland, and I had charge of the boats on each occasion. I am acquainted with every form of disengaging hook, and was called some years ago to give evidence before a committee at the Admiralty to inquire into the best system of lowering boats at sea. I am amused to hear Mr. Hill and Mr. Mark Robinson talk of their experience. I should like to know where they have gained it—not at sea certainly. The time to test disengaging gear and gain experience is at sea, in rough weather. I was once lowered in a jolly boat with four men from a frigate under double-reefed topsails, off the Cape of Good Hope, to the assistance of a lad who had fallen overboard, and succeeded in saving

him, but was an hour and a quarter before I got on board again. This is only one instance of my many experiences in lowering boats and saving men who had fallen overboard. I should like to have seen Mr. Hill or Mr. Mark Robinson in that boat. I should like the opportunity some day of showing an invention here, which has been tried and is now in use, to show how to carry boats with safety and lower them with promptitude. I maintain that boats should be carried outside the davits, and at the same time be inboard, and not outside the davits, and consequently outside the ship. These davits and releasing chocks are fitted to a number of ships, notably to H.M. Post-office Telegraph ship *Monarch*, and the *Ceylon*, of the Board of Trade. I have a disengaging hook, which is admitted to be the simplest, cheapest, and most effective hook out.

Captain C. Penrose FitzGerald, R.N.: I applied for Rees's hook for boats of last ship, but was refused because they were not on the establishment.

Mr. W. J. Rees: I was the first man who had thimbles in lower blocks, and hooks on slips. Many Naval officers I see here know how dangerous the hooks were in lower blocks.

Rear-Admiral P. H. Colomb (Associate): My Lord, I just want to say one word to clear up an apparent discrepancy in the paper. On page 451 surprise is expressed as to only two or three boats in Her Majesty's service being fitted with these slip hooks. As a matter of fact, there is no particular object in fitting slip hooks of any kind to more than the two or three boats which are likely to be used at sea in an emergency. There is no object in fitting the ordinary boats of a ship, which are only lowered after preparation in harbour, and so on. There is no object in fitting expensive or delicate arrangements to them, and therefore the Admiralty, as far as I understand, will be quite right to limit the supply to two or three boats likely to be lowered in an emergency. As to the other project of allowing captains their choice, instead of having compulsion applied to one particular system, we know that practice is historical in the Navy. Everything that we do, nearly all the improvements that we have had of any character, have been treated in this way. I may mention one which will explain the whole arrangement. At the battle of the Nile it was permissible to the captains commanding Nelson's ships, either to have a mizen gaff or to have the old lateen mizen yard in its place, and gradually in the course of time the lateen yard was beaten, and the gaff came in permanently; and so, I think, as soon as one hook has distinctly beaten all the others, we shall have a universal system in the Navy.

Mr. E. J. Hill (Associate): My Lords and gentlemen, in reply to Mr. Robinson's remarks, I should like to say this: The first thing he objects to is, that he does not like my calling his plan a slip hook. All I can say, then, gentlemen, is that if his hook is not, and does not completely fulfil the conditions of a slip hook, I do not know what a slip hook can be.

Mr. Mark Robinson: A tumbling hook.

Mr. E. J. Hill: It does not work as a tumbler hook. Now, with regard to his disliking my calling it a modification of Kynaston's system, in the Blue Book which was issued, containing the report of the Committee of 1872, it distinctly stated that it is a modification of Kynaston's hook, and therefore I may properly call it so.

Mr. Mark Robinson: I think in that Blue Book two plans are suggested, one of which I proposed myself, and the other a modification of Kynaston's, proposed also by myself. I think Mr. Hill must be referring to those.

Mr. E. J. Hill: They are both exactly the same system, and worked on the same principle, and, therefore, a modification. Mr. Robinson said that he had not brought out his invention till 1881, and that I, being a frequent visitor to the Dockyards prior to that date, had obtained all the business from the year 1872 to 1881. I may remark simply, that whenever I went to the Dockyards during all those years, I had the pleasure of meeting his most energetic cousin, and I was very glad to meet him, and when the officers with whom I had conferred heard him, and then heard me, I was the more fortunate—I do not know why—in getting the orders for the fitting of the majority of those ships.

Mr. Mark Robinson: I do not think I said so.

Mr. E. J. Hill: As a matter of fact, the hooks were sold in 1872, and continued to be supplied until 1881, although Mr. Robinson says he only commenced doing business in 1881.

Mr. Mark Robinson: It is quite true they were not made until 1881.

Mr. E. J. Hill: It was a very long trial from 1872 to 1881, and in his circular issued in 1880 he says they were adopted and kept in store at the Dockyards. Now, Mr. Robinson speaks of the new hook, and as to my introducing the word "automatic." I quite admit it is a mistake to use that word, as there are some conditions in which it is not automatic, and I have discontinued it in my old plan; but I see here that the word is made use of, by which I mean at times automatic. It is not necessary to be worked by a weight, because in the *Monarch* telegraph ship, where they had a good trial of this, I adopted the plan in the trial of throwing a little kedge anchor over the side in their working boat on the off side of the ship, so as just to have a little strain on that anchor to do the work, and I am going to fit the hooks you see on the table to the Italian Navy cruiser *Piemonte* to work in the different ways described in my paper. I think that is all I need say with regard to that. I am very glad to hear that the Admiralty are giving Mr. Robinson a good many orders, but I would also say that I think there must be something wrong in his plan, as he has never been able to induce some of the numerous shipowners to use it.

Mr. Mark Robinson: I have never applied to them.

Mr. E. J. Hill: Captain FitzGerald, I know, is a true believer in the old service hook, but whether we can ever join together to find one hook that will do as much as he says the service hook can do, all I can say is, that if my new hook does not do this, I shall be very glad to join the ring, and assist in every way I can to achieve that end. I quite agree with him that we should not fight in the matter, and I hope he does not think that we are such competitors in business as we appear to be in argument. With regard to his saying that he has seen accidents happen with these inventions to boats at sea, I would also remark that there have been numerous accidents, as in the *Ariadne*, with the old system which he still believes in. Then Admiral Colomb made a remark about it only being necessary for certain boats on a ship to be lowered in certain emergencies, such as a man overboard, when the object of course is to get them away as quickly and safely as possible in order to rescue the man; but I think you can imagine that if there are twenty-four people in the boat which is leaving the ship after a collision before the ship founders, that you would like to have the same speed in getting the other boats away as you had in lowering the boat to pick up the one poor man who had fallen overboard, and therefore it must be a good principle, surely, to have all the boats of a ship fitted with a system to enable them to be lowered speedily and safely, and if men of experience grant there is reason and common sense in this, what is the reason a good plan worthy of being fitted to two boats should not be applied to the whole of them

carried on a ship? (Hear, hear.) When I was before the Institution with regard to this system, I had never seen a Navy boat, and my thoughts and ideas were troubled when I was shown the heavy slings to which my hooks were to be fitted for trial. Mr. Rees helped me in this. The great trouble I have had in the Navy has been the fitting of it in the sling. It is difficult, but I can assure you that it always works well in a rough sea, if it be at all looked after. If that old hook is not perfect, I hope the one I have shown you to-day will be so.

The PRESIDENT: For the last hour I thought I was again in the Inventions Exhibition, where I passed a great many weeks in concert and co-operation—not co-operation, because I was merely there in a sort of official capacity—but in concert with, and under the advice of, a most eminent jury of experts. We saw all these hooks, and rings, and tackle, and boats, day after day, and week after week, and I merely wish, as your President, to make this one remark, that I hope that this will not be regarded as an advertising debate, because we rather set our faces against that. I am delighted to see such cordiality and such friendship between two rival gentlemen, who seem to me the best of friends, and who really have been. I hope you will consider it as discussing a question of most vital importance to human life, the question of boat lowering, and lowering boats under adverse circumstances. That is, really, what they have been doing. It is not a question of Robinson *v.* Hill, or anything of the sort, but they have been really discussing a most important matter, both to the Mercantile Marine and to the Royal Navy. I should like to put it on that ground, for once make this a means of recommendation of one invention against another, there is simply no end to it, and it is not one of our functions. I merely wish to make that remark, and I am quite sure you will allow me to offer to Mr. Hill, and those gentlemen who have joined in the discussion, your united thanks for the light which they have thrown on this subject. We do not say that one plan is better than another, but we have discussed a very important matter connected with the saving of life at sea.

CONCLUDING PROCEEDINGS.

Mr. B. Martell (Vice-President): I have a very pleasant duty to perform, which is one I have had the honour of performing before, and I must say that every time I do it the pleasure to me increases; it is that of proposing a vote of thanks to our esteemed President, Lord Ravensworth. We appreciate more and more, with which I am sure you will agree with me, the manner in which he presides over us. His kindness, his consideration, and his urbanity are everything that we can desire, and certainly more than we sometimes deserve. An instance has this evening just occurred of his kindly consideration in allowing us to have a little amusement in connection with our dry discussions, which I am sure you will all have appreciated; therefore, gentlemen, I have very great pleasure in proposing a vote of thanks to Lord Ravensworth, for the very able and kindly manner in which he has presided over us during the present meetings.

Mr. H. Morgan (Vice-President): I have very great pleasure in rising to second the proposition. When we consider that a nobleman in the position of Lord Ravensworth leaves the high duties to which he is accustomed, and comes here year after year to preside over us, day after day and night after night, at these meetings, I think that we must all acknowledge that we are under very great obligation to his Lordship. We have also to consider this: we most of us here are professional men, and can understand pretty well what is going on. His Lordship is not a professional man, although he has sat here a good many years, and although throughout all his life he has been closely connected with matters of shipbuilding and the shipowning interest, still I often think that his Lordship, having to sit and to follow all that is said, is somewhat at a disadvantage, and especially when we consider that we, who sit down here, if we have a paper or a speech that does not particularly interest us, can look round at the pictures and admire them, or go outside and think of anything else that has greater interest for us, while his Lordship has to keep up one continuous strain of attention, and has always to keep his mind fixed on what is going on. When we consider those disadvantages, I am sure that must increase the feeling of obligation that we know ourselves to be under to Lord Ravensworth, and therefore I have very great pleasure in seconding the vote of thanks which Mr. Martell proposes.

The President: Mr. Martell, Mr. Morgan, and gentlemen, I rise to thank you; and, in the best way that words will permit, to express to you my most grateful thanks for the kind manner in which you have received the proposition made and seconded by those two gentlemen who have last addressed you, and for the kind and friendly expressions which they have made use of. I am very happy to think that they are both my friends, and friends now of very long standing, and friends for whom I have very great respect. I can only express my gratitude for the very kind terms in which they have expressed themselves with regard to the duties which it is my privilege and pleasure to discharge. Perhaps you will allow me for a few moments to occupy your time. I will not be long; but there are a few remarks which I should like to make at the conclusion of this, our most successful meeting. I think, gentlemen, that though at one time the Council had a little anxiety as to whether our agenda paper would be as full as usual, the result of our three days' sittings must be a matter of the highest gratification to you all. I have been here now for a good many years, and I have never heard discussions so replete with interest, or discussions which excited so much interest as these which have occupied your attention for the last few days. Now it is perfectly natural that, on an occasion like this, when the public mind is exercised on what I consider to be "the great question

of the day"—namely, our national security, and the increase of our Navy—that public attention should centre very much on those questions which dealt mainly with the increase of our Navy, and with the designs of the ships to be built for that purpose. It was perfectly natural that public interest should centre largely in that, and we have had discussions that I think will convey information in the clearest possible way throughout the length and breadth of the land, with regard to a subject upon which the nation's interest is centred at this moment. I think, moreover, that I observe from year to year a growing interest in the proceedings of this great Institution, in which I myself take so much pride, and, I am bound to tell you, pleasure. I think that is shown by the notice that is taken of our proceedings from year to year, an increasing amount of notice by the leading organs of the public Press. I think that is a pretty significant sign, and this year, of course, it is most natural that the public outside should have looked to such an Institution as this, composed of experts and men of the highest degree of scientific education, of intelligence, and of knowledge—practical knowledge of the subjects brought under discussion—for information and for counsel which they may safely follow. Now I venture to say that the great subject of the designs which occupied your attention in the earlier part of our meeting was a discussion of infinite value for the guidance of the nation, and I venture to think, and I will appeal to you whether I am right or wrong in my conception, that the designs came very well out of the ordeal. At one time the controversy which had been raised appeared to many of us—certainly to myself—to bristle with hostility; but when you bring great minds together, and enable them to discuss calmly their differences, great minds very often approximate with regard to their ideas, and I am happy to think that that which threatened hostility ended in reconciliation and amity. Nothing has given me greater pleasure than to observe that. At the same time able men, great thinkers, retain their convictions, and if they did not retain them they would not be worth listening to. All that we expect to do in a great Institution of this kind is to court and encourage a conflict of intelligent opinion, and thereby you get the truth. A man is none the worse for retaining his convictions. As I said before, he has a right to retain them. I have no doubt that some who have engaged in that conflict of opinion still retain their opinions; but I say distinctly that the designs have come out of the contest with flying colours.

Now I want to turn, if you will allow me for a moment, to a subject very near and very dear to my own heart, and that is the Merchant Navy. All Her Majesty's subjects, and Parliament, which represents the public, are naturally interested, deeply interested, in the Royal Navy, and we hear a great deal about the Royal Navy; but we do not hear as much about the Merchant Navy as I think it deserves, except within these walls, and that is my apology to you for having dared on the first day of our meeting to detain you longer than I otherwise should have done with matters appertaining to the Merchant Navy. But when I remember, and when you know, that the Merchant Navy of England is the foundation of her greatness and her strength, I will never lose an opportunity of, as far as I possibly can, promoting the interests of that mighty service. I was born and bred amongst shipowners and managers of ships, and we are very proud indeed of the Merchant Navy that we turn out in the north of England at this moment. We have had some papers of great importance to-day, and I wish particularly to allude to Professor Lewes's paper. I do not think since I have had the honour of sitting in this chair I have heard a paper of more general public utility and value than that paper. The question of corrosion has excited a great deal of public attention, and it has been dealt with to-day and well discussed, and I cordially hope that the information derived, or rather the information furnished, and the discussion that ensued upon the information, will come home to the heart of every shipowner in this country, because I am perfectly certain of this, that it is impossible to

estimate the amount of money wasted in past times in very valueless compositions and elements for the purpose of avoiding that serious danger of corrosion and fouling of the bottom of ships. I do think that the truth was brought out this afternoon, and the truth will always prevail, provided it is properly disseminated. Then we had this afternoon the fulfilment of a pledge by our most respected and most eminent member, Mr. Froude. He read two papers of such consummate excellence, but such profound learning, that it was exceedingly difficult to get up much of a discussion upon them; but depend upon it, that the course of profound research and investigation in which he has been engaged for so many years has borne fruit, and will continue to bear fruit; and as long as health and strength are given him, he will continue this laborious research into one of the most profound problems that can occupy the attention of scientific men. We honour the name of Froude from the memory we have of his father, and we are happy to see those talents, that ability, and that industry inherited by his son. Now, gentlemen, it is not right for me to detain you at any length; it is a very bad reward even to have detained you so long for the kind expression of your opinion.

But there is one more word I must say. We have had the name of Sir George Airy mentioned to-day, and very prominently put forward—the late Astronomer Royal. It is fifty years since that distinguished man took up the subject of compass adjustment, and I think it is only fair to remind you of the fact that for fifty years that great man has been engaged on the very subject which has formed the text of the very valuable paper read this evening. I do not want to detain you further, but I must remark this: so great has been the interest excited by the papers read that our sittings have been of most unusual length, and I am afraid that our kind friends, who lend us this hall, year after year, have been a little nervous at the length of time these sittings have continued. Because they want the hall sometimes themselves, and they want to have the hall dusted and cleaned out, and we have occupied this hall at rather an unusual length. But still the interest of our subjects is our excuse, and I am quite sure they will think it is a good excuse. I am no longer a young man, or so vigorous as I used to be, and I think it is quite time that you should consider the matter of my successor, because I do not feel myself at all competent to fill this chair. (No, no.) I have told you that over and over again. But I hope whoever succeeds me will live to see the day when we shall have a hall of our own, where we can command our own time, and then the probability is that we shall meet at 11 o'clock a.m. and sit until 12 p.m. How long the President will live under those circumstances it remains for the future to prove. I could not do it. I thank you with all my heart for your kindness. Every year that I come here I occupy the chair with renewed pleasure, and with feelings of my utter incompetence to fulfil properly the duties which devolve upon me.

Mr. Mark H. Robinson (Associate): My Lord, I am charged with a pleasant duty, in being selected to propose our usual vote of thanks to the Society of Arts for the use of this room. For many years the Society of Arts has put us under this obligation, and although the obligation is a pleasant one, it is much to be desired, as your Lordship says, that we should have a hall of our own, and I hope, for one, to live to see that time. On the Wednesday of our present meeting we so overflowed, even this spacious hall, that the very accountants and officers of the Society of Arts were crowded out of their rooms; but we are entitled to set off against this, that we have read papers and have held discussions of great importance to the country, and not unworthy even of the hall of that famous Society. We have, indeed, cause to be grateful to the Society of Arts, and I beg to move that a vote of thanks be passed to the Society for the use of their room.

Mr. J. H. MacIlwaine (Member) : My Lord, I have very much pleasure in seconding the vote of thanks so very ably proposed by Mr. Robinson. Speaking for those who live at a considerable distance, we look forward to these meetings of ours as a sort of break in the monotony of a country life ; and I say that that pleasure is greatly enhanced by the excellent accommodation placed at our disposal by the Society of Arts, and I have very much pleasure in seconding the resolution.

[The resolution having been put to the meeting was carried with acclamation.]

Admiral A. F. R. De Horsey (Associate) : My Lord and gentlemen, I also have been charged with a most pleasant duty, which is to propose a vote of thanks on the part of this meeting to the Council of this Institution. I am sure we all feel how much we are indebted to the Council for the amount of labour bestowed on their duties, and for the care they take in the selection of papers, a very responsible duty. Having been an associate of this Institution nearly thirty years, I am enabled to say that during that time I have been struck with the amount of pains which must have been taken by the Council to maintain its excellence. I will not proceed further in speech-making—it is foreign to my nature—but I would ask you to pass a hearty vote of thanks to the Council.

Rear-Admiral A. F. R. Colomb (Associate) : My Lord and gentlemen, I have very great pleasure in seconding the resolution moving a vote of thanks to the Council. I cannot help expressing my personal feeling how much I have been struck this session by the greatly increased attendances we have had for every paper ; it is not that one paper has attracted a large attendance, but that the hall has always been well filled from first to last, and that shows, I think, how admirably the papers produced before the Institution have been selected by the Council. I think that we must all have felt strongly what our noble President spoke of, in reference to the good humour which was produced by the first paper when temper of another character was probably somewhat anticipated, and that good humour is, I take it, an augury for the continued success of the meetings of this Institution. I think that we are confirmed in that view by the fact that apparently that good humour passed on, continued to the end, and overflowed at the very last meeting of the session. I have very much pleasure in seconding the resolution.

Mr. J. Macfarlane Gray (Member of Council) : My Lord and gentlemen, in the name of the Council of this Institution I have great pleasure in thanking you for the hearty expression of confidence you have now conveyed to us. A notice was received by several of the members of your Council a short time ago that they were not to be candidates for seats in the London County Council. I am thankful that no hindrance, but rather encouragement, is offered by those in authority to members of the Admiralty or Civil Service serving on this Council ; and I am sure every one of us considers it quite as great an honour. I am but a humble member, but there are names of men of great distinction on your Council, and I am certain there is not one of those who does not consider himself additionally honoured by being chosen by you as a member of this Council.

The President : I am sure you have every right to be tired of the sound of my voice, and I am quite sure that I am tired of it myself, but there is one thing I must ask you to do, and that is to allow me to propose, with your sanction, and, I hope, approval, a vote of thanks to our excellent, and hard-working, and courteous Secretary. No one knows so well as the President himself the value of our really good Secretary, because he not only combines great diligence, great courtesy, great attention to every appeal that is made to him in the large correspondence he has to conduct, but he is a very able critic himself, and very well acquainted with almost all the subjects which are discussed here.

and can hold his own with many of those who bring forward those subjects. He is a very eminent mathematician, and a distinguished Cambridge student, and, depend upon it, he would be a very difficult man to tackle on some technical subjects. I will not say more, but it is due to him to return, as I trust you will, by acclamation, your thanks to him for his very valuable services.

The Secretary (Mr. G. Holmes): I am deeply grateful to you, my Lord, for the more than kind way in which you have spoken of my very small services, and to you, gentlemen, for the way in which you have received what his Lordship has said. I am greatly afraid that the part I play here is only a mechanical one; but such as my services are I am sure that it gives me the greatest possible pleasure to render them to the best of my ability, and I hope I shall long be able to continue to do so.

MEMOIR OF DR. JOSEPH WOOLLEY, M.A.

The Council announces with sincere regret the death of Dr. Joseph Woolley, M.A., who was one of the original founders of the Institution, and one of its most active supporters. Joseph Woolley was born at Petersfield, in Hampshire, on June 27, 1817. His father was a physician who, shortly after the above-mentioned date, removed his practice to London, where his son was educated, first at Brompton Grammar School and afterwards at St. Paul's School, which was then in the City. In 1834 he went to St. John's College, Cambridge, and in 1840 took his degree, having obtained the high positions of third wrangler and second Smith's Prizeman. In the natural course of things he was elected a fellow and tutor of his college, in which capacity he numbered many distinguished men amongst his pupils, foremost amongst them having been Professor Adams, the well-known astronomer and discoverer of the planet Neptune. In 1846 he relinquished his fellowship, and married Ann, daughter of Robert Hicks, Esq., of Afton, Isle of Wight, and was shortly afterwards appointed to a curacy in Norfolk. In the following year he was presented by Bishop Stanley, of Norwich, to the living of Crostwich, near Norwich.

In the year 1848 he commenced that part of his career which was of most interest to the members of this Institution, for he was then appointed Principal of the School of Naval Construction at Portsmouth Dockyard, and retained this post till the school was abolished by the Admiralty in 1853. During the short time that this establishment was in existence Dr. Woolley numbered amongst his pupils many of the best-known Naval architects of the day, including Sir Edward Reed, Sir Nathaniel Barnaby, Mr. Barnes, Mr. Crossland, and Mr. Morgan.

Dr. Woolley's high mathematical attainments, and the interest which he took in applying his scientific knowledge to the solution of many of the intricate problems connected with ship design and construction, enabled him to render the most valuable services to the science of Naval Architecture, and much of the progress which has taken place during the past forty years must be attributed to his labours, both as a teacher and as an investigator. His appointment to the School of Naval Construction put him in a position to learn how very backward the theory of Naval Architecture was in this country, and he earnestly set to work to remedy the then existing state of things, with a success to which the Transactions of this Institution bear continuous testimony.

When at Portsmouth he wrote an able treatise on Descriptive Geometry, a subject which was then almost unknown in Great Britain. He also arranged a complete course of studies for the use of his students, embracing every subject bearing on Naval Architecture. He afterwards wrote a second treatise on the application of descriptive geometry to the problems of naval construction, but the manuscript was only just completed when the Portsmouth School was abolished, and the book unfortunately was never published. On vacating his post at Portsmouth, Dr. Woolley was appointed Admiralty Inspector of Schools, and in 1858 he was nominated one of H.M. Inspectors of Schools. In these capacities he rendered important services in organising education for the Navy.

In 1860 the Institution of Naval Architects was founded by a small body of gentlemen, several of whom unfortunately are now no longer living. The story of the foundation has been well told in the first volume of Transactions, by its organising Secretary, now Sir Edward Reed, K.C.B., M.P., F.R.S. In this foundation and in the subsequent work of carrying on the Institution, Dr. Woolley took, directly and indirectly, a large share. At the opening meeting, the very first paper, on the appropriate subject of the Present State of the Mathematical Theory of Naval Architecture, was from his pen, and he subsequently read many other important papers, a list of which is given below.

As is well known, one of the earliest efforts of the Institution was directed towards influencing the Government to re-establish a technical School for Naval Constructors, and when, in 1864, the Royal School of Naval Architecture and Marine Engineering was founded, under the joint auspices of the Admiralty and the Committee of Council on Education, Dr. Woolley was very rightly appointed Inspector-General and Director of Studies. He held this post under somewhat modified conditions till, in 1873, the School was merged in the Royal Naval College at Greenwich.

Shortly after the loss of H.M.S. *Captain*, in 1870, Dr. Woolley was nominated by the Admiralty a member of Lord Dufferin's Committee, which was appointed to consider many vexed question relating to the design of ships of war. This Committee, in their very able report, threw much light on the difficult subjects which they were appointed to consider.

When the qualities of H.M.S. *Inflexible* were called in question, the Admiralty appointed a committee, of which Admiral Sir James Hope was chairman, to investigate the subject. Dr. Woolley was one of the members of this committee, and his participation in its labours was almost the last public duty in connection with Naval Architecture which he was called on to perform.

Dr. Woolley invented a very elegant method of ascertaining the volume of the displacement of a ship or other floating body. When the Institution was founded he

was, in recognition of his valuable services, elected as one of its first Vice-Presidents, and in 1884 the Council bestowed on him the exceptional honour of electing him an Honorary Member. His services on the Council were not less valuable than his scientific contributions to the Transactions of the Institution, and his high qualities endeared him to all his colleagues, by whom his loss is much regretted.

The following papers were read by Dr. Woolley before the Institution :—

On the Present State of the Mathematical Theory of Naval Architecture. Vol. I. 1860.

On the Rolling of Ships. Vol. I. 1860.

Postscript to Mr. Froude's Remarks on Mr. Scott Russell's Paper on Rolling. Vol. IV. 1863.

On the Education of Naval Architects. Vol. V. 1864.

On the Bows of the *Helicon* and *Salamis*. Vol. VI. 1865.

On the Theory of Deep Sea or Oscillating Waves. Vol. XVI. 1875.

MEMOIR OF SIR WILLIAM PEARCE, BART., M.P.

By the death of Sir William Pearce the profession of Naval Architects loses one of its most active and intrepid members, in the midst of his career, and at a time of life when most men are at the zenith of their powers.

Sir William Pearce was born in 1833, at Brompton, adjoining Chatham, in the dockyard of which town he served his apprenticeship. He remained in the Dockyard till the year 1863, when he was engaged by Lloyd's Register as one of the surveyors of the Society. In the following year, however, he once more engaged in practical shipbuilding by accepting the post of manager to Messrs. R. Napier & Sons, at Glasgow. In this office he acquired his first experience in the design and construction of Transatlantic passenger steamers, the *Pereire* and the *Ville de Paris*, two well-known vessels of the Compagnie Générale Transatlantique, having been built at Messrs. Napier's during the time that he was manager. In the year 1869 the premature death of Mr. John Elder took place, and Mr. Pearce was invited to join Messrs. John Ure and Mr. J. L. K. Jamieson in carrying on the famous business at Fairfield, and on the retirement of the two latter gentlemen, in 1878, he became sole partner in the firm. In 1885, shortly after his return to Parliament, he turned the business into a limited liability company, under the title of the Fairfield Shipbuilding, Engineering and Ordnance Company, Limited, he himself assuming the position of Chairman of the Board.

During the period that Sir William Pearce was connected with the Fairfield Works over 450,000 tons of shipping were turned out, including many of the most famous Transatlantic and Australian liners, such as the *Alaska*, the *Arizona*, the *Austral*, the *Orient*, the *Umbria*, and the *Etruria ;* some of these vessels, by the speed they have regularly maintained, and by the general comfort of their arrangements, have marked epochs in the history of passenger traffic at sea. One of the most curious works of Naval Architecture turned out of Fairfield was the Royal Russian yacht *Livadia*, which was constructed from the designs of Admiral Popoff, and which is fully described in Volume XXII. of the Transactions of the Institution.

Sir William Pearce was not only a builder, but also a very large owner of ships. He was closely connected with several important companies, such as the Guion, the Pacific Mail, the New Zealand, the Scottish Oriental, and the Great Western. He was

a good friend to the cause of technical education, and it was to his generosity that Glasgow University owes the buildings pertaining to the Chair of Naval Architecture, which it now possesses (see pp. 74 and 79 of the current volume of the Transactions). In 1885 Mr. Pearce (as he was then) was first returned to Parliament as representative of the Govan division; and two years afterwards, on the occasion of the Queen's Jubilee, he received a Baronetcy. He was for some years a Member of Council of this Institution, and was also a Member of the Iron and Steel Institute, and of the Institution of Engineers and Shipbuilders in Scotland; but, probably owing to the extreme commercial activity of his life, he was unable to take much part in either the management or the scientific work of these bodies. His death this year, at the early age of 56, leaves a gap which will not easily be filled.

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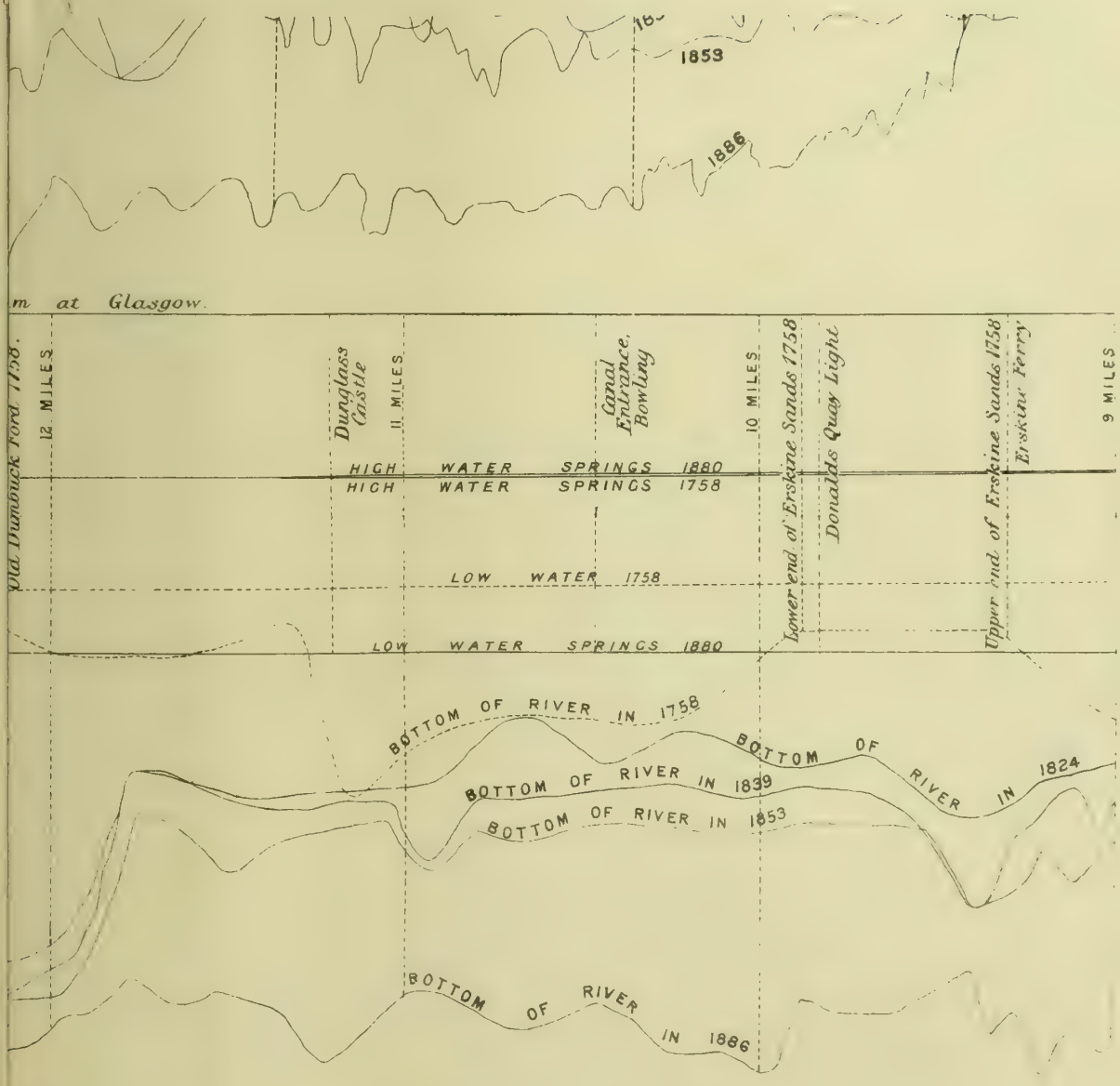
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Old Dumbuck Ford 1758.
12 MILES.
Dunglass Castle
11 MILES.
Canal Entrance, Bowling
10 MILES.
Lower end of Erskine Sands 1758
Donalds Quay Light
Upper end of Erskine Sands 1758
Erskine Ferry
9 MILES
HIGH WATER SPRINGS 1880
HIGH WATER SPRINGS 1758
LOW WATER 1758
LOW WATER SPRINGS 1880
BOTTOM OF RIVER IN 1758
BOTTOM OF RIVER IN 1839
BOTTOM OF RIVER IN 1824
BOTTOM OF RIVER IN 1853
BOTTOM OF RIVER IN 1886
Vertical Scale.
20
30
40
50 Feet

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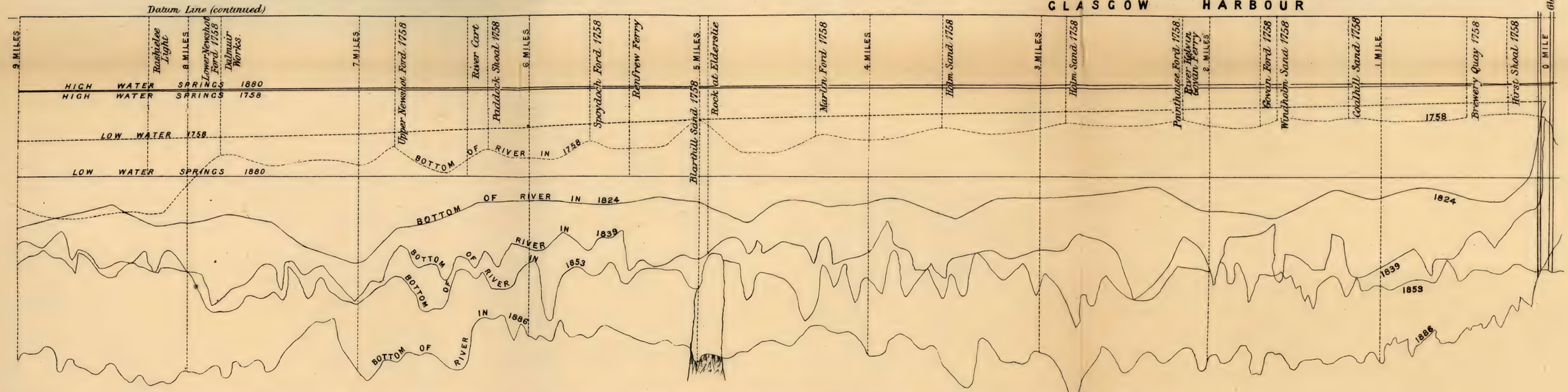
To Illustrate Mr. J. Deas' Paper on the River Clyde.

CLYDE NAVIGATION.

LONGITUDINAL SECTION OF THE RIVER CLYDE SHEWING THE DEPTHS OF THE CHANNEL IN THE YEARS 1758, 1824, 1839, 1853 AND 1886 RESPECTIVELY.



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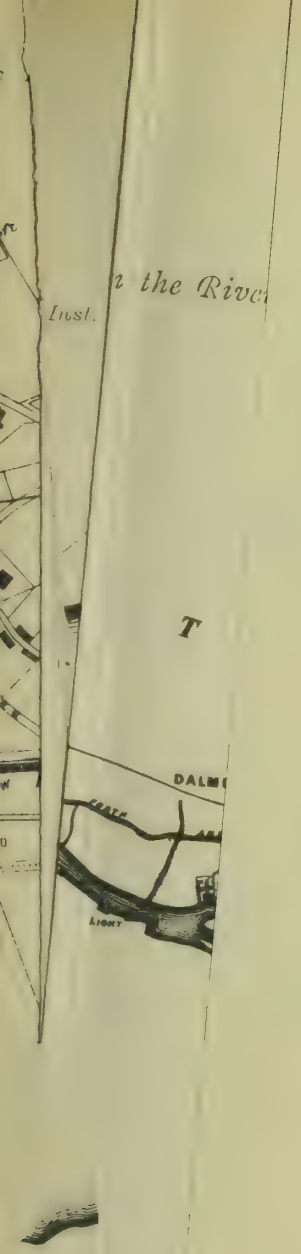
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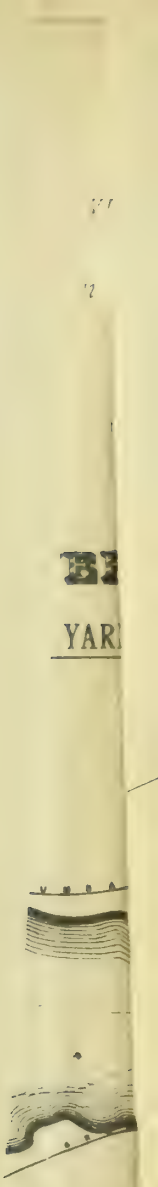
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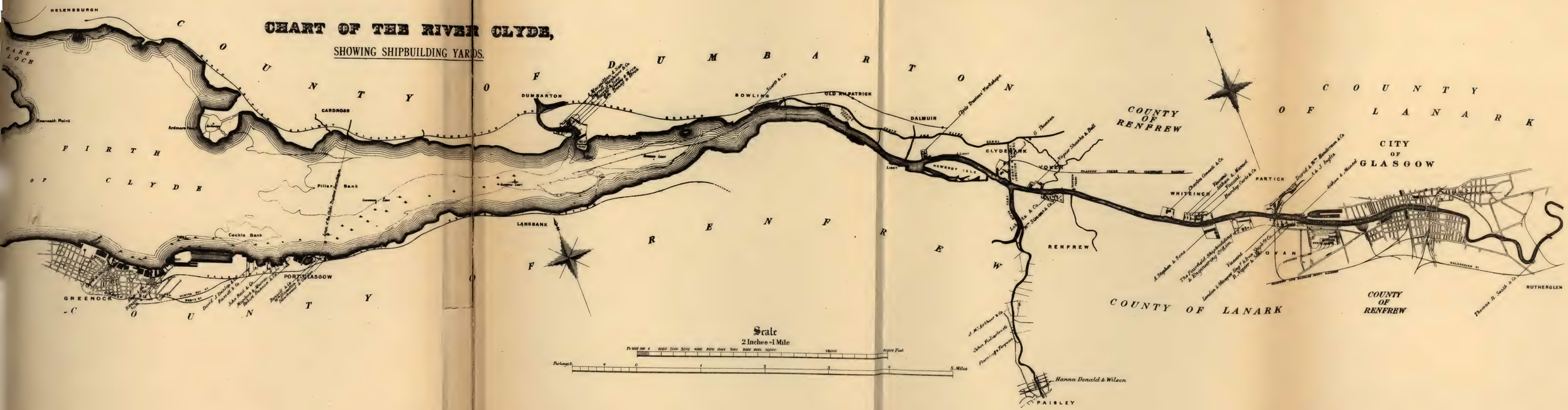
CHART OF THE RIVER CLYDE,

SHOWING SHIPBUILDING YARDS.



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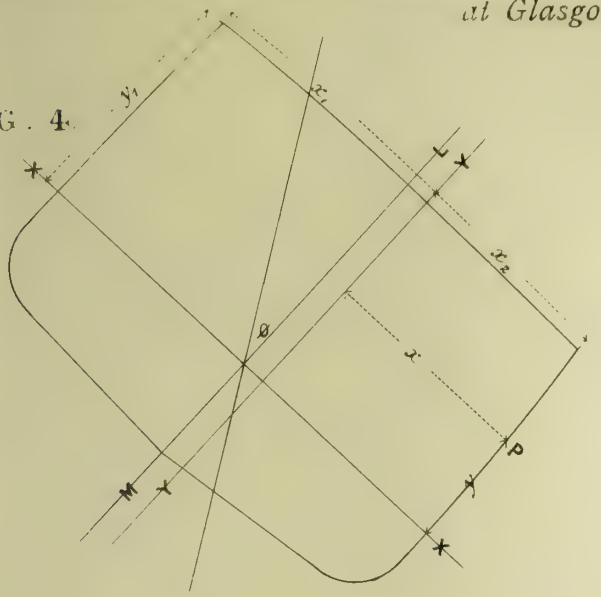

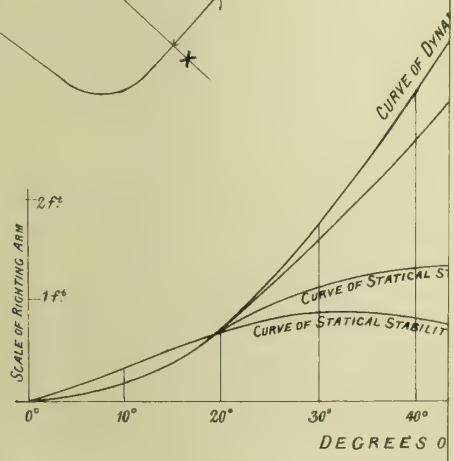

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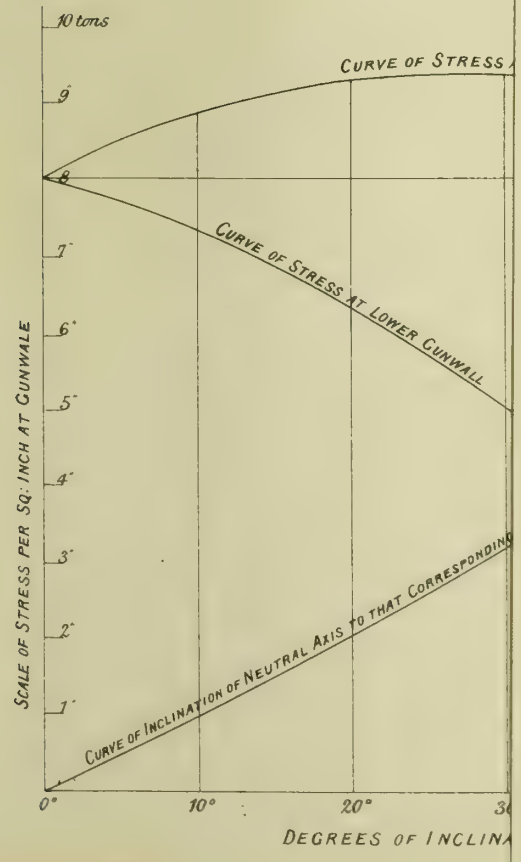

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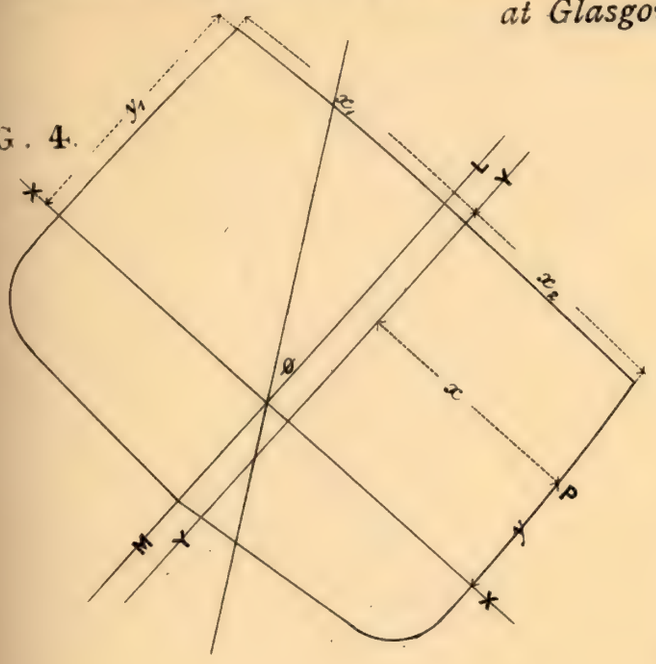
FIG. 4.



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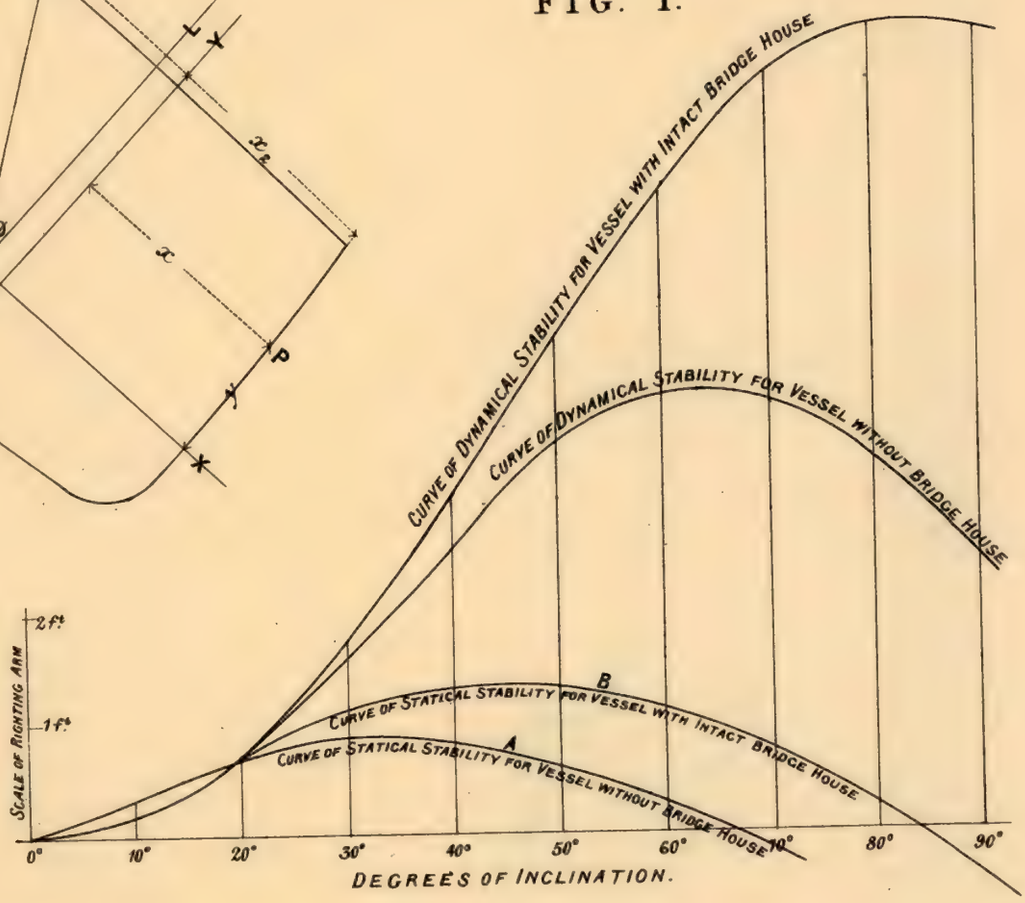
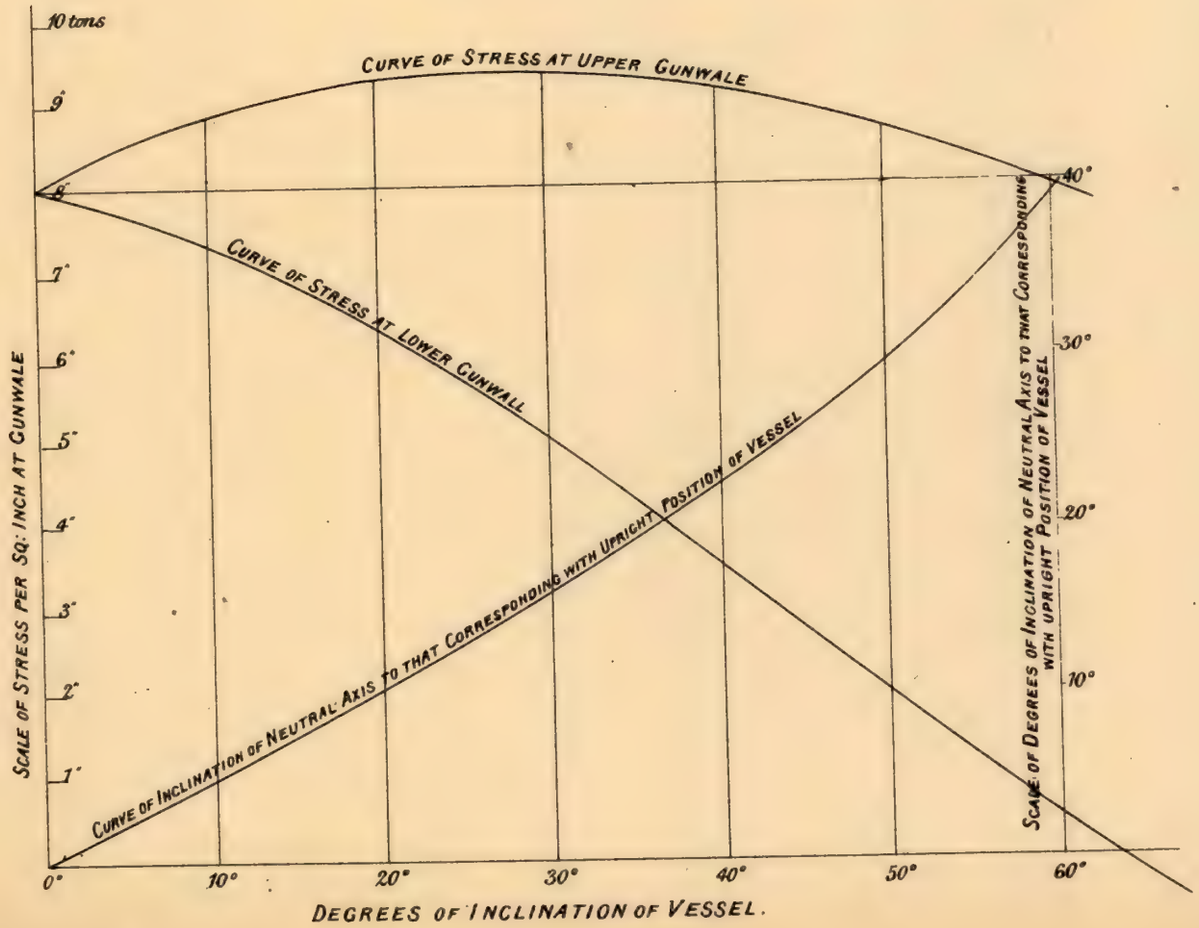
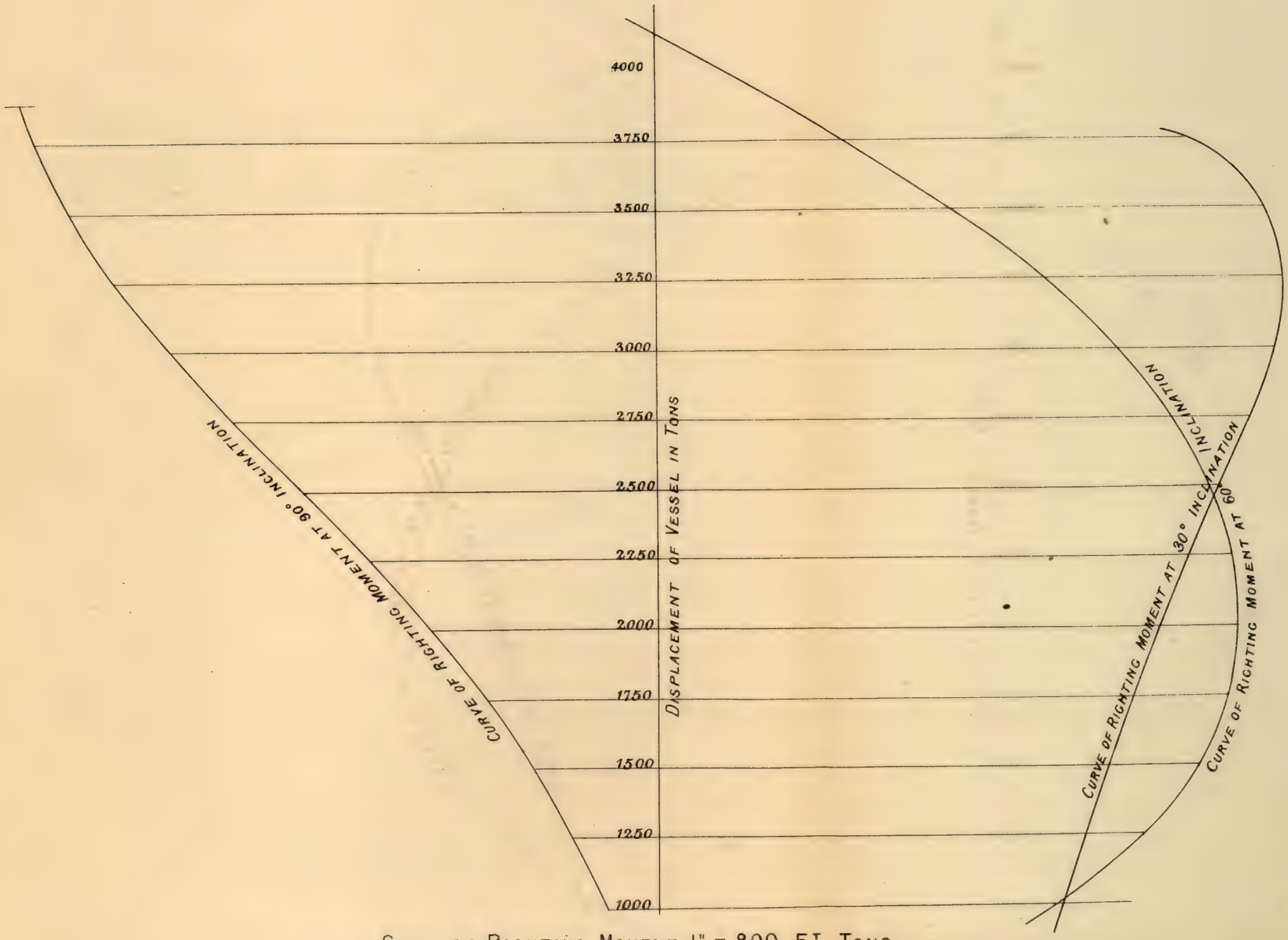


FIG. 3.



To Illustrate Professor P. Jenkins' Paper on the Course of Instruction in Naval Architecture at Glasgow University.

FIG. 2.



SCALE OF RIGHTING MOMENT 1" = 800 Ft TONS.

To Illustrate Major N. Soliani's Paper on the Steam Trials of the Royal Italian Ironclad "Lepanto"

FIG. 1.

ARRANGEMENT OF ENGINES AND BOILERS.

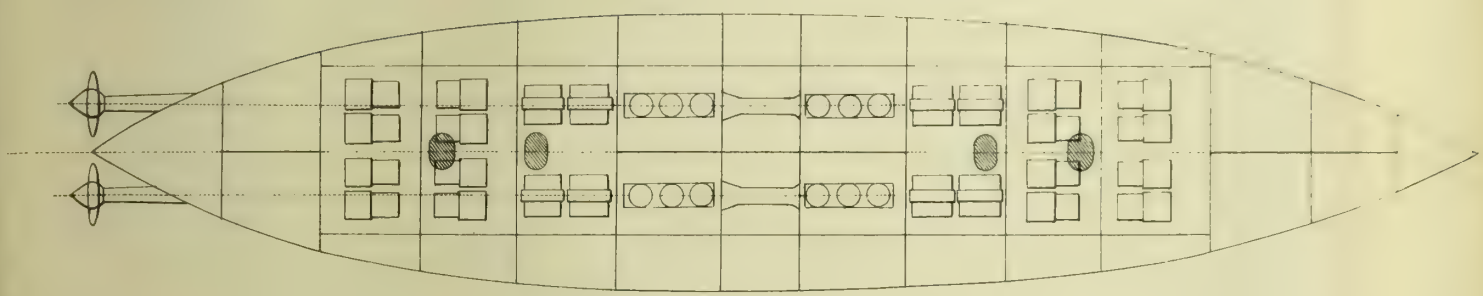
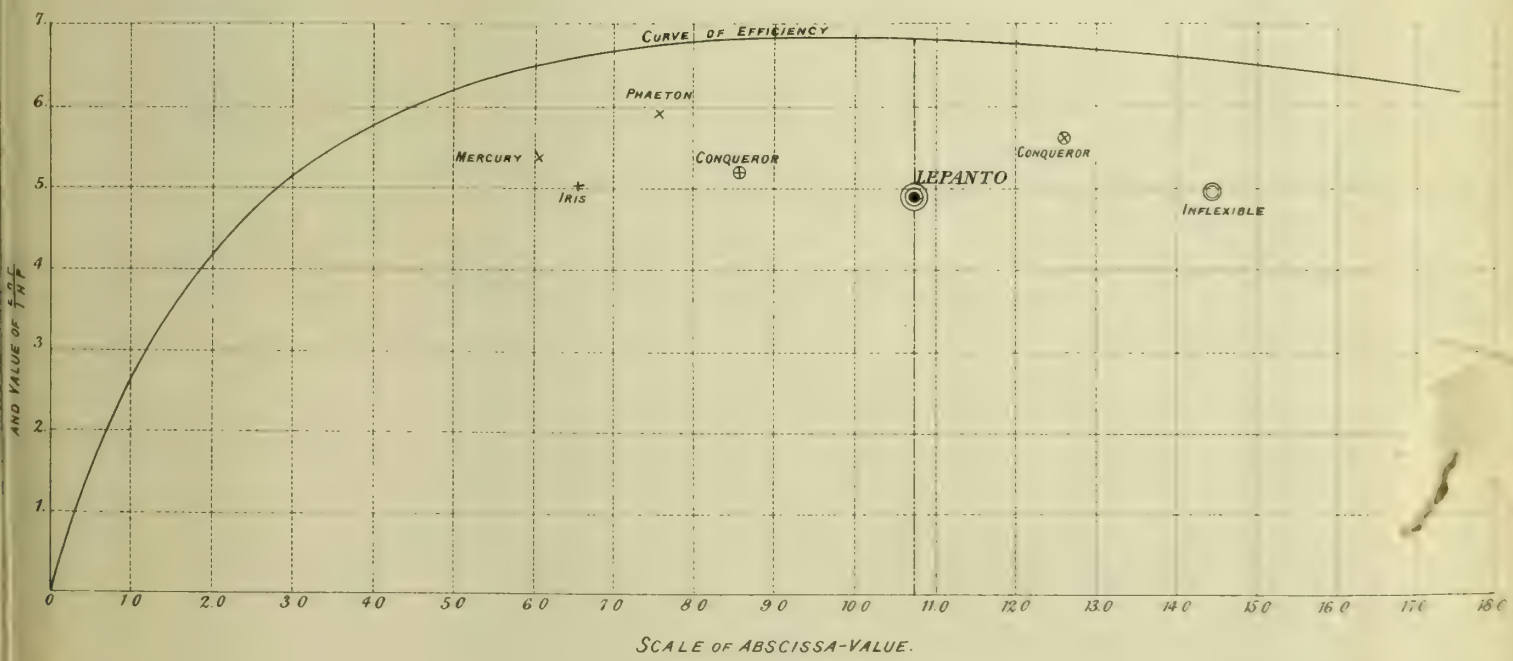


FIG. 4.



To Illustrate Major N. Soliani's Paper on the Steam Trials of the Royal Italian Ironclad "Lepanto"

FIG. 2.

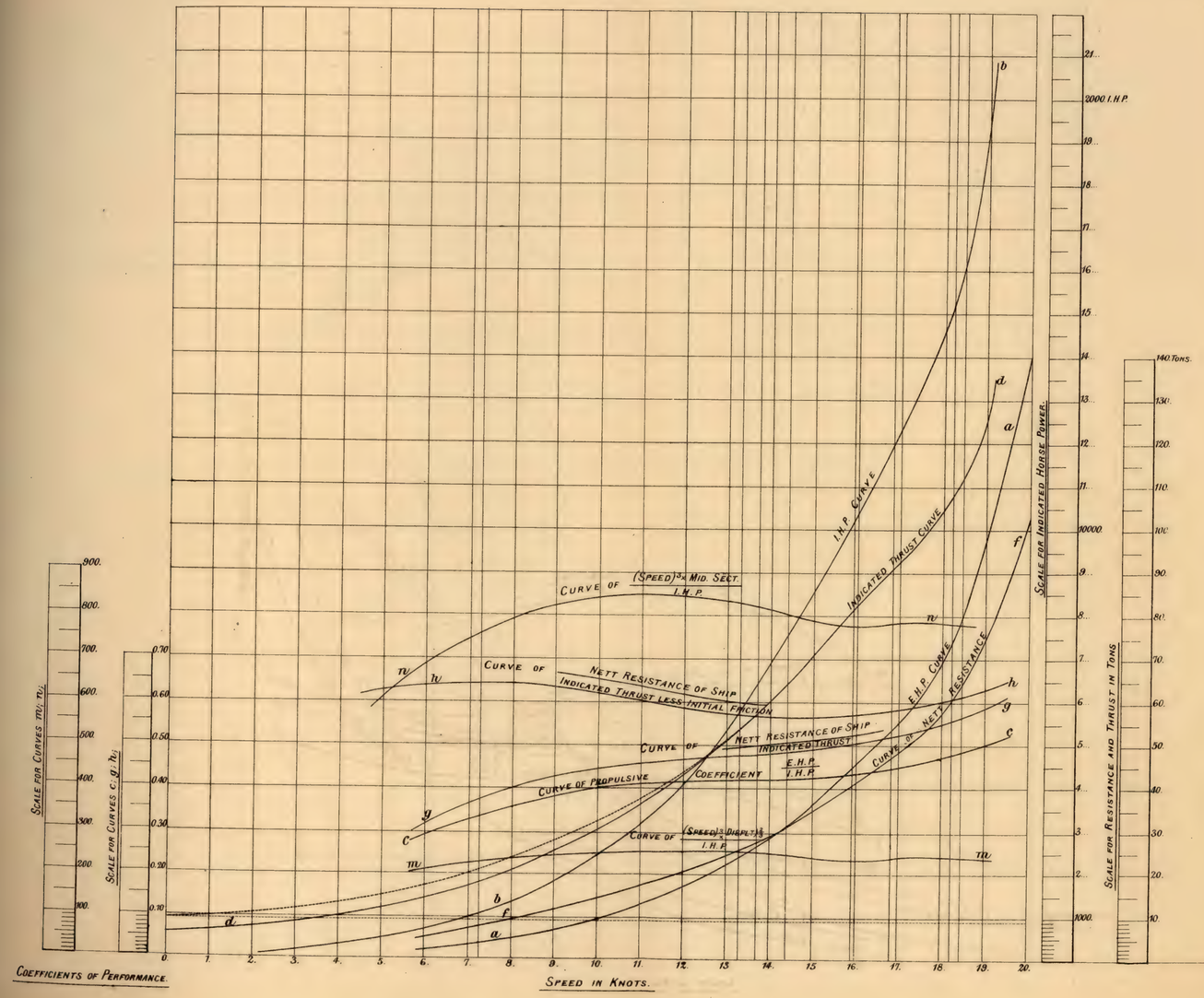
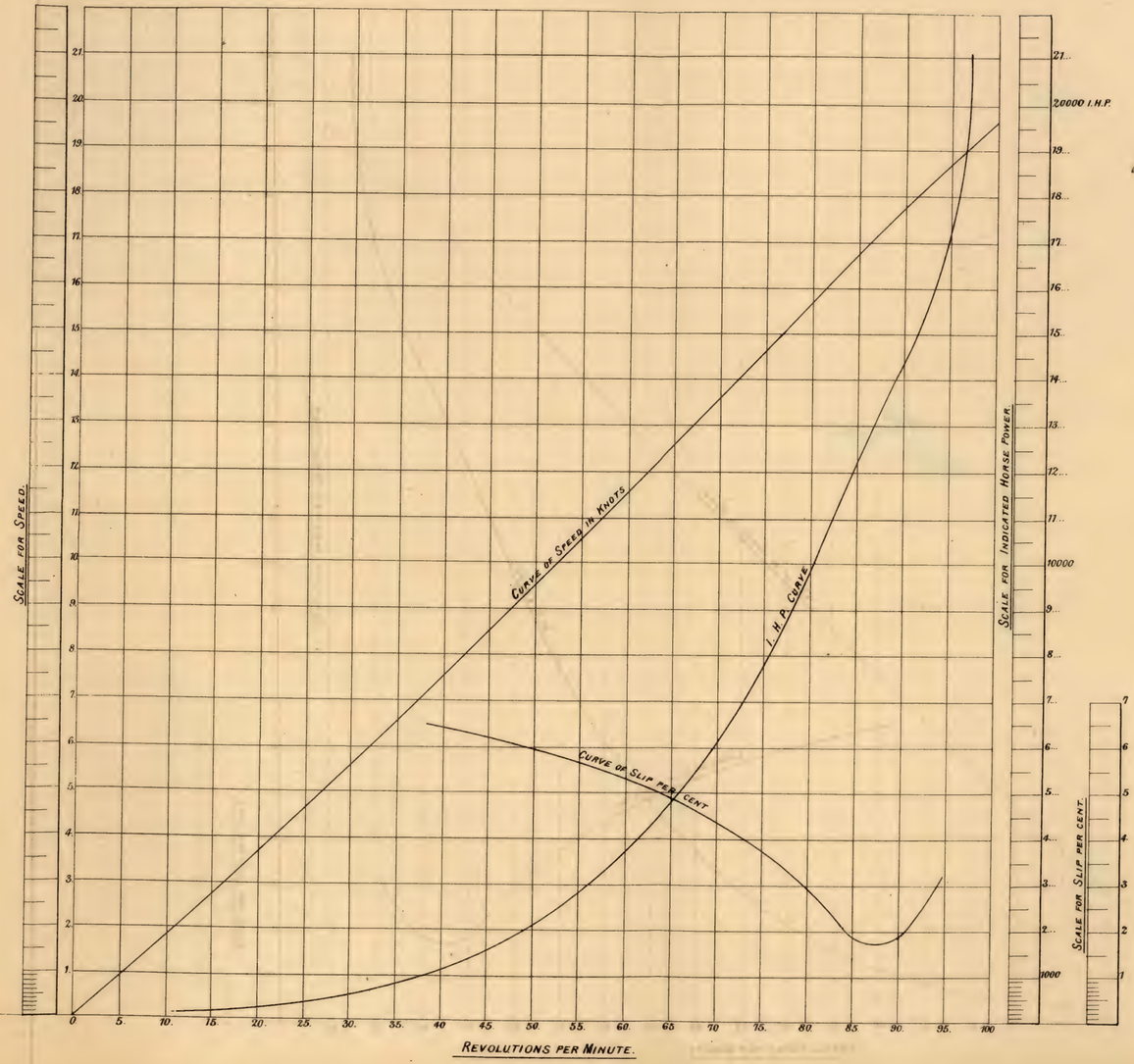
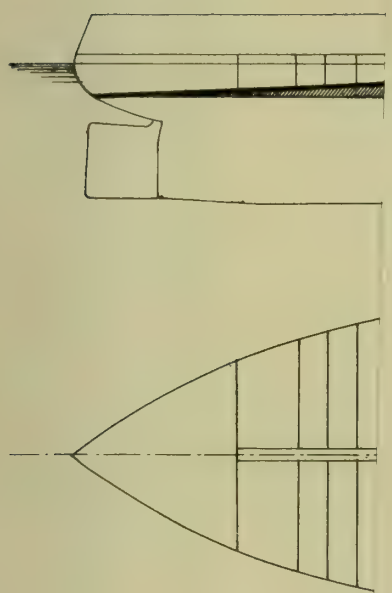
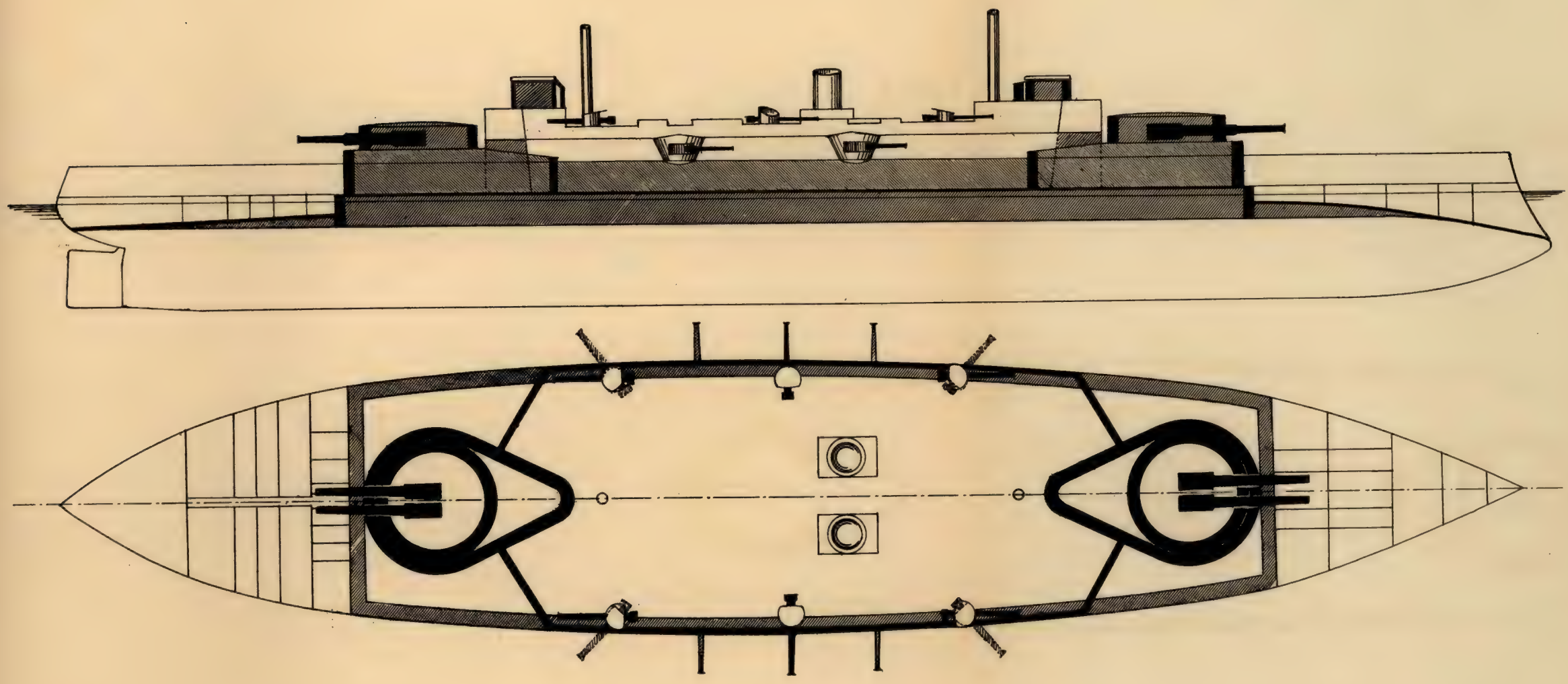

I.H.P. CURVE
INDICATED THRUST CURVE
E.H.P. CURVE
CURVE OF NETT RESISTANCE
CURVE OF (SPEED)³ × MID. SECT. / I.H.P.
CURVE OF NETT RESISTANCE OF SHIP / INDICATED THRUST LESS INITIAL FRICTION
CURVE OF NETT RESISTANCE OF SHIP / INDICATED THRUST
CURVE OF PROPULSIVE COEFFICIENT E.H.P. / I.H.P.
CURVE OF (SPEED)³ × DISPL.⅔ / I.H.P.
SCALE FOR CURVES m, n.
SCALE FOR CURVES c, g, h.
SCALE FOR INDICATED HORSE POWER.
SCALE FOR RESISTANCE AND THRUST IN TONS
COEFFICIENTS OF PERFORMANCE.
SPEED IN KNOTS.

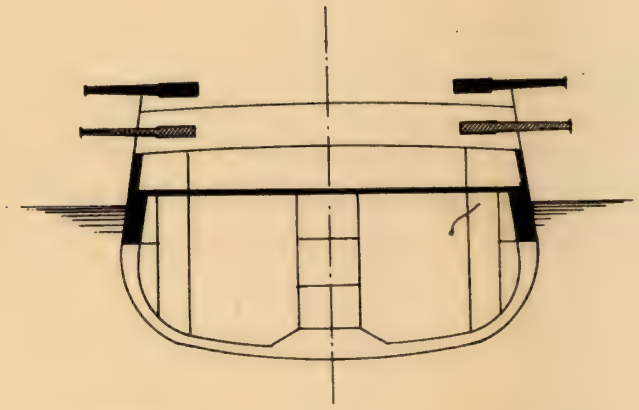
FIG. 3.


CURVE OF SPEED IN KNOTS
I.H.P. CURVE
CURVE OF SLIP PER CENT.
SCALE FOR SPEED.
SCALE FOR INDICATED HORSE POWER.
SCALE FOR SLIP PER CENT.
REVOLUTIONS PER MINUTE.



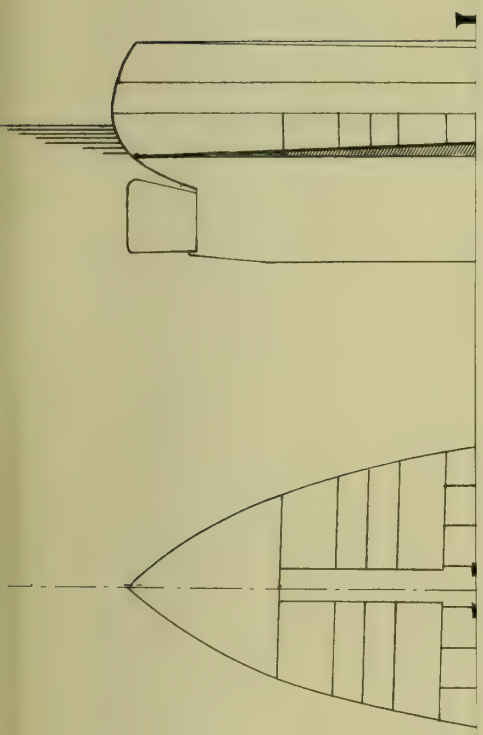
To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.



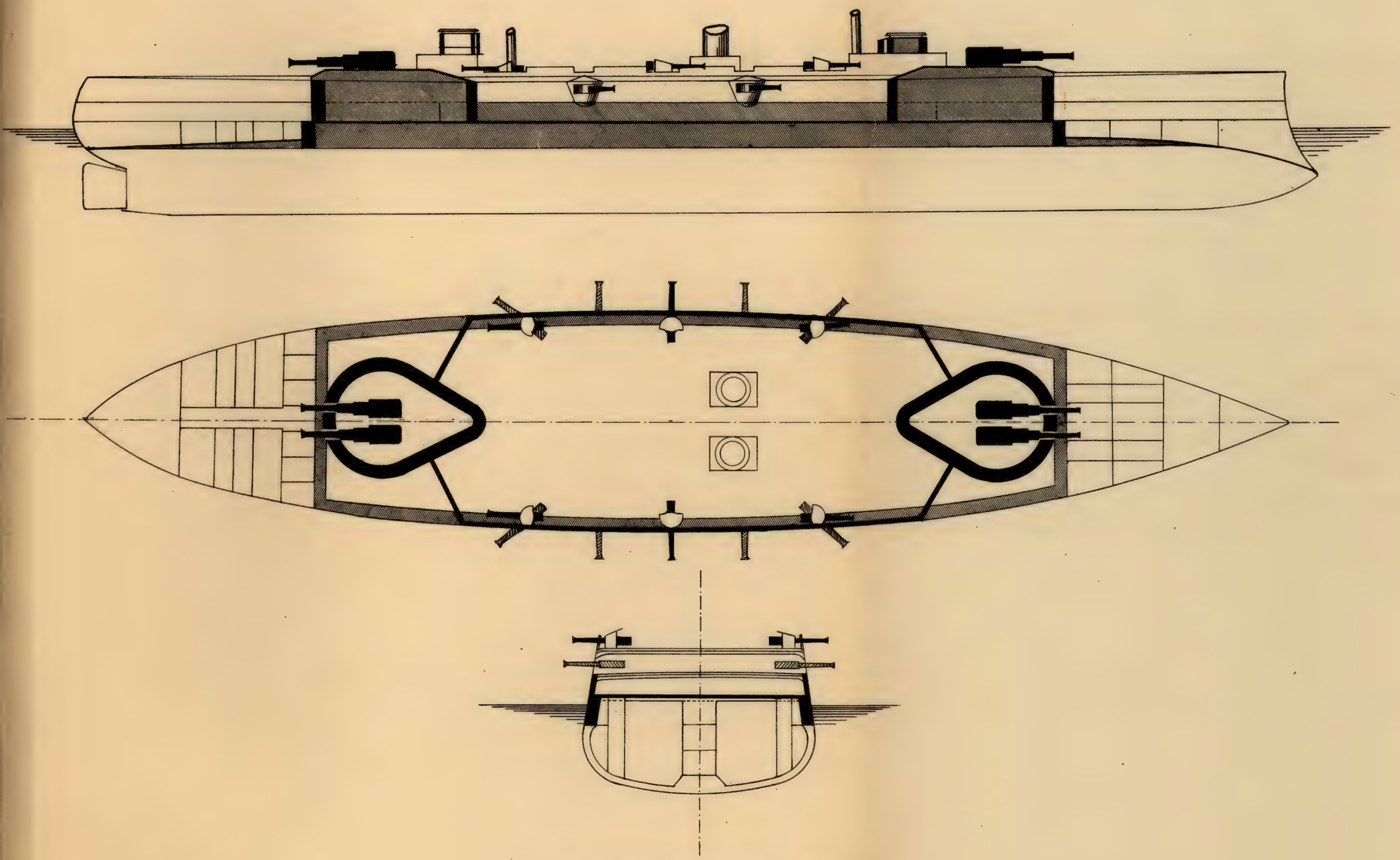


NEW TURRET SHIP
DESIGN

To

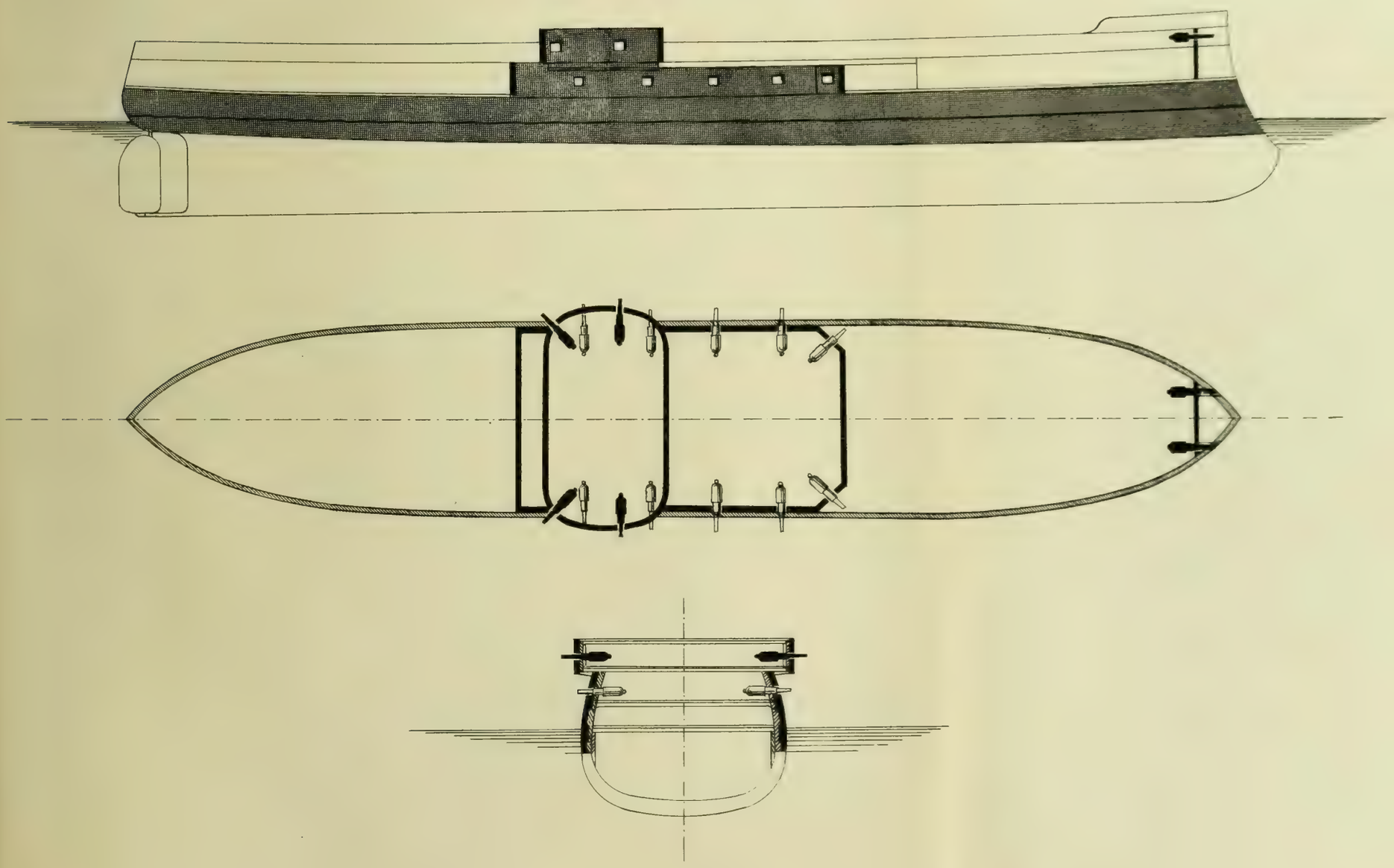


To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.



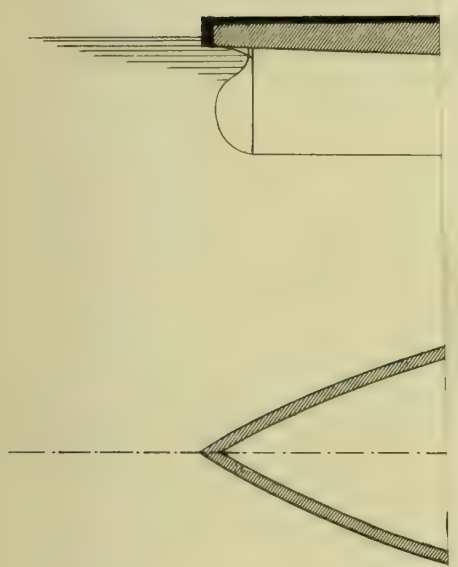
"NEW BARBETTE SHIP",
DESIGN.

To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships



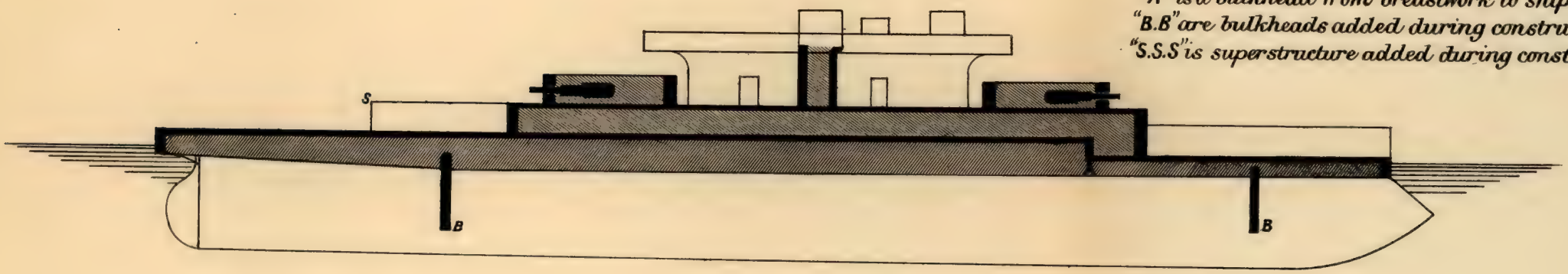
"SULTAN"

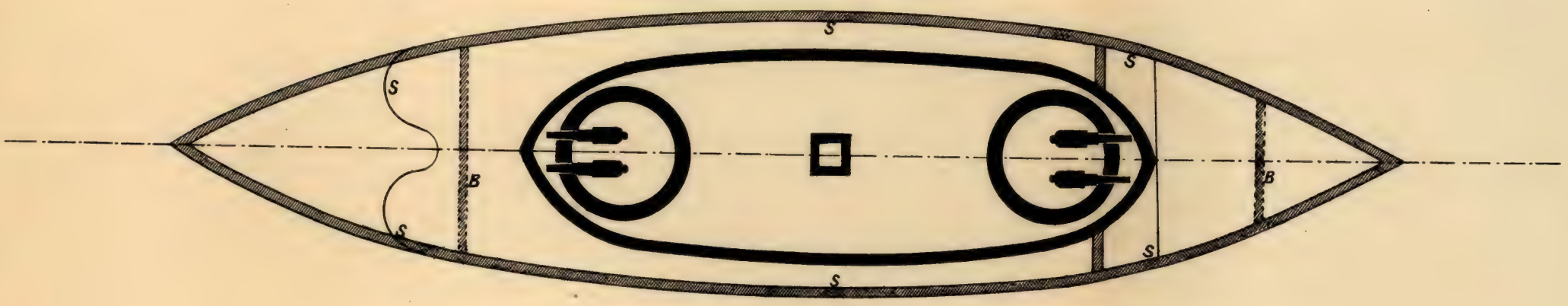
To Illustr

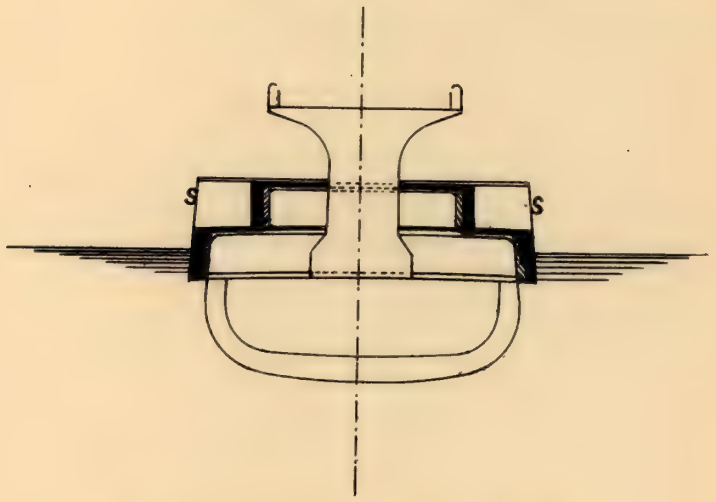


To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.

"A" is a bulkhead from breastwork to ship's side.
"B.B" are bulkheads added during construction.
"S.S.S" is superstructure added during construction.

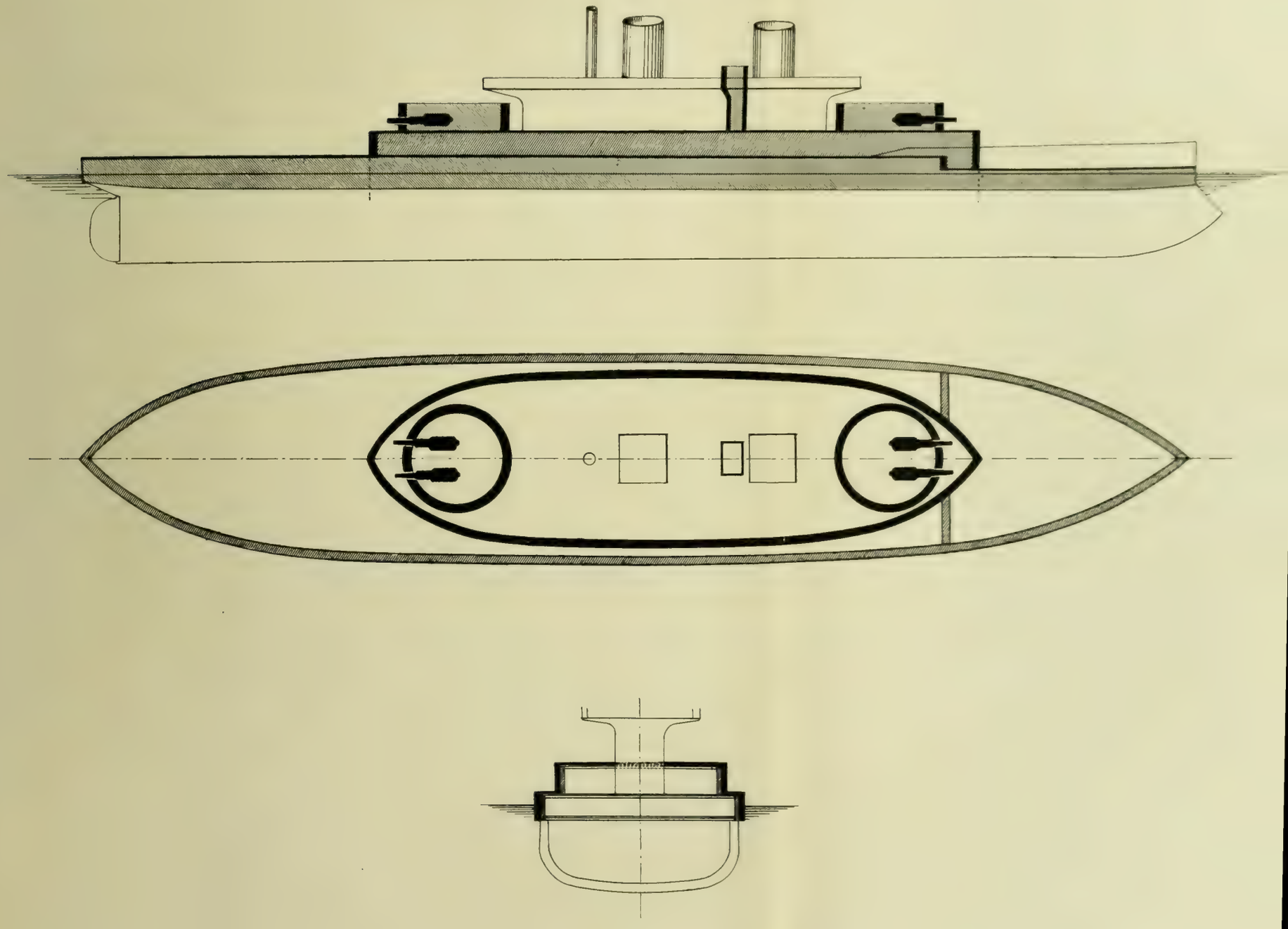






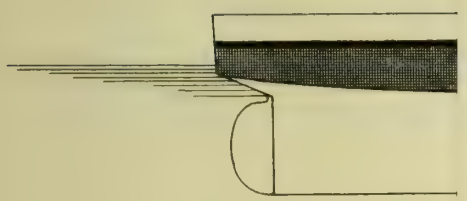
"DEVASTATION".

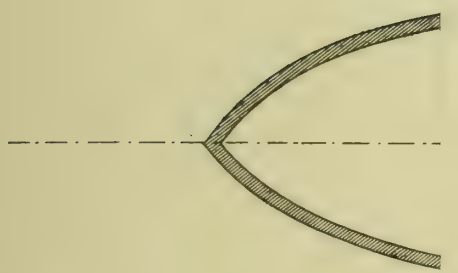
To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.



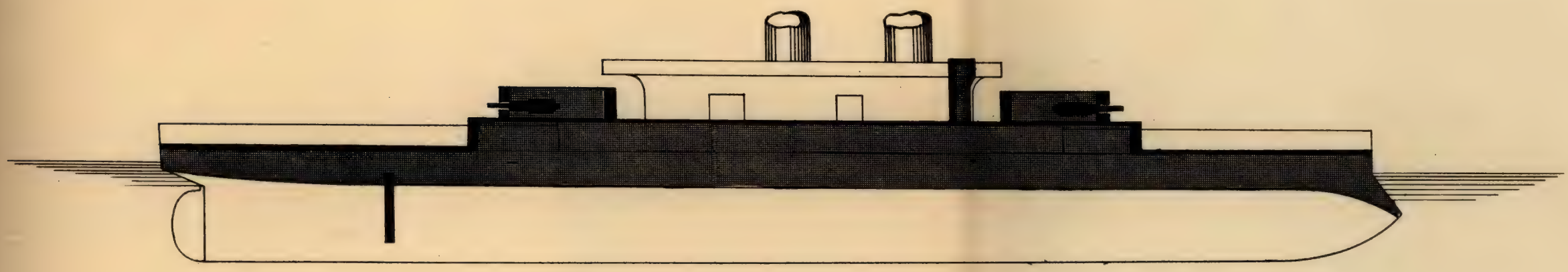
"FURY"

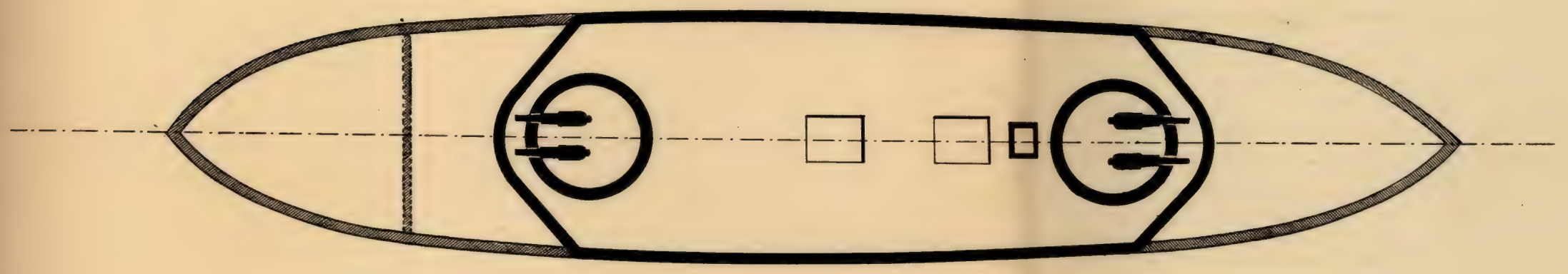
To Il

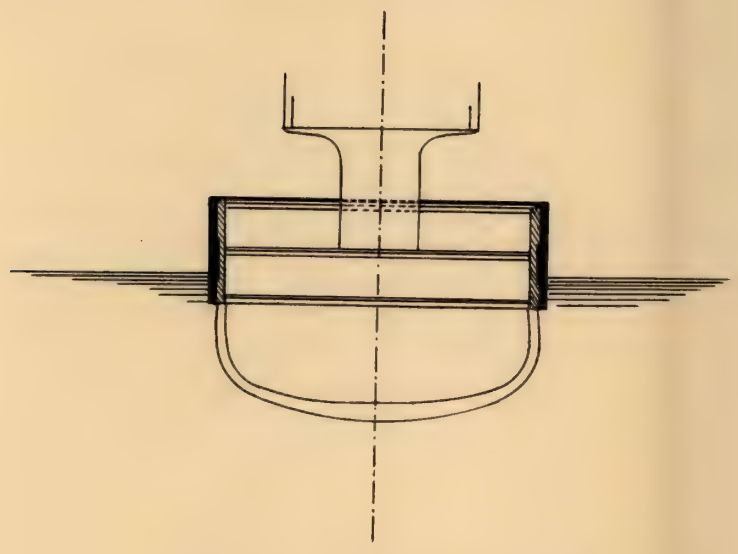




To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.

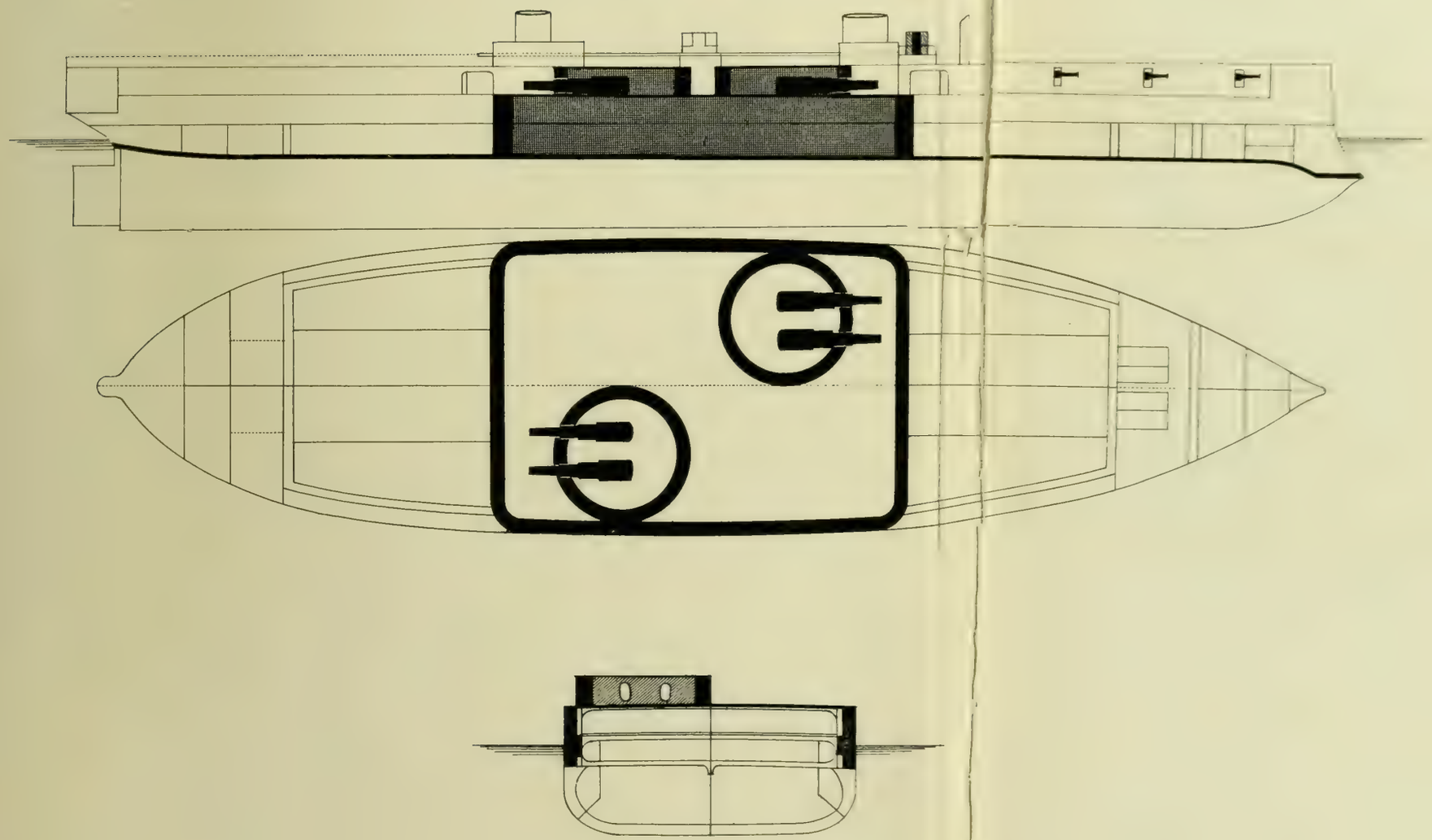






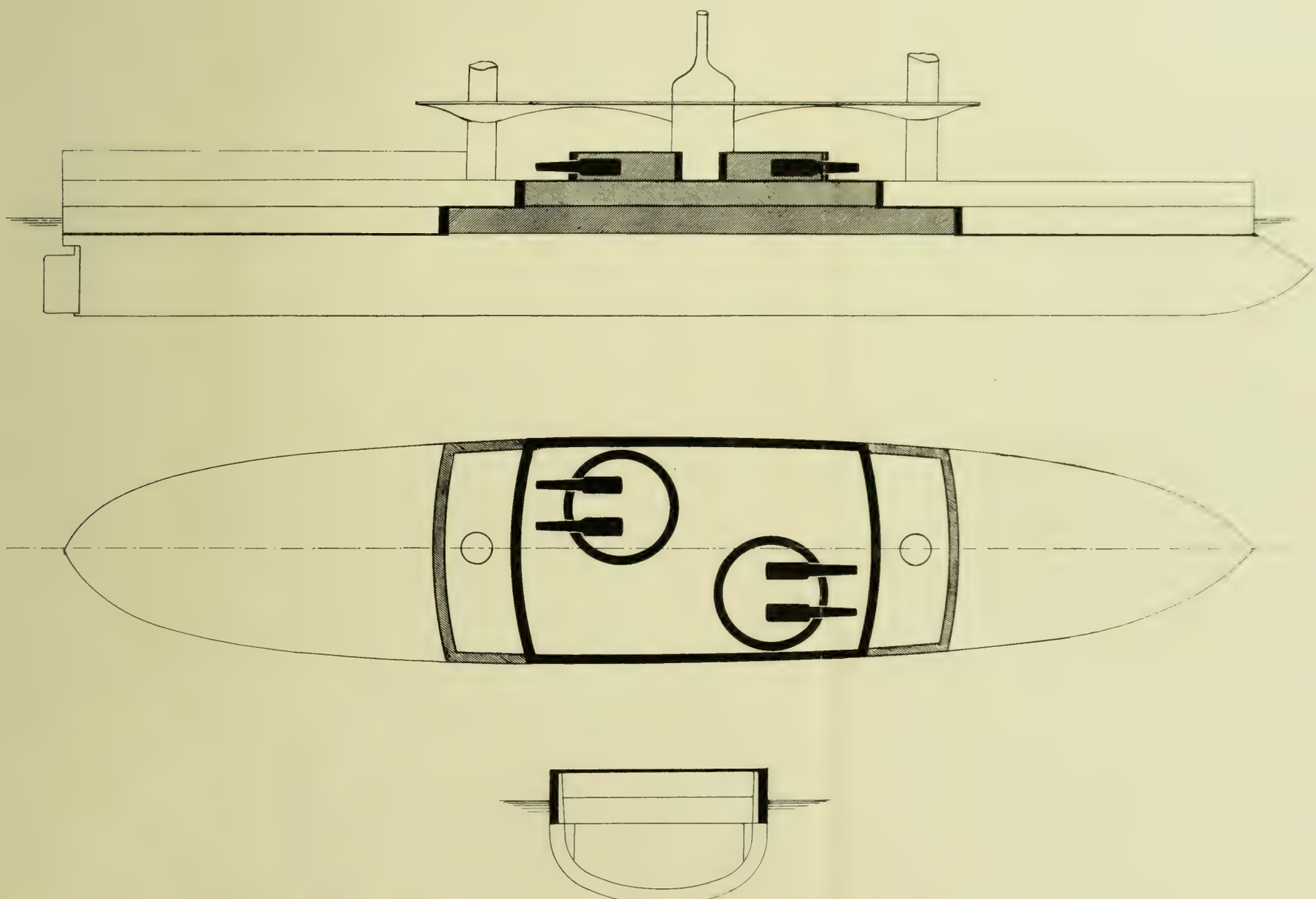
"DREADNOUGHT"

To Illustrate Mr. W. H. White's Paper on the Designs for the New First class Battle Ships



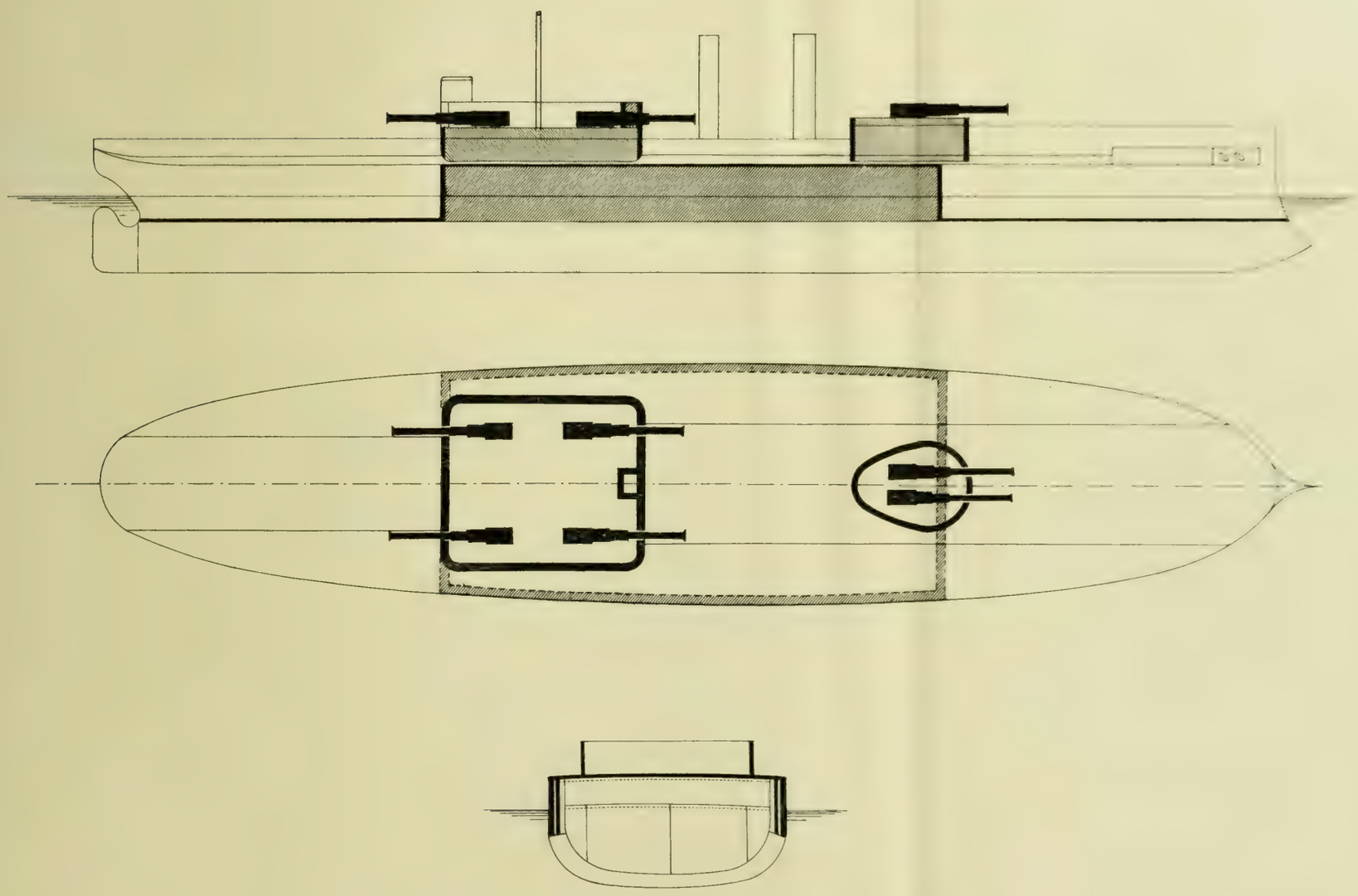
"INFLEXIBLE"

To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.



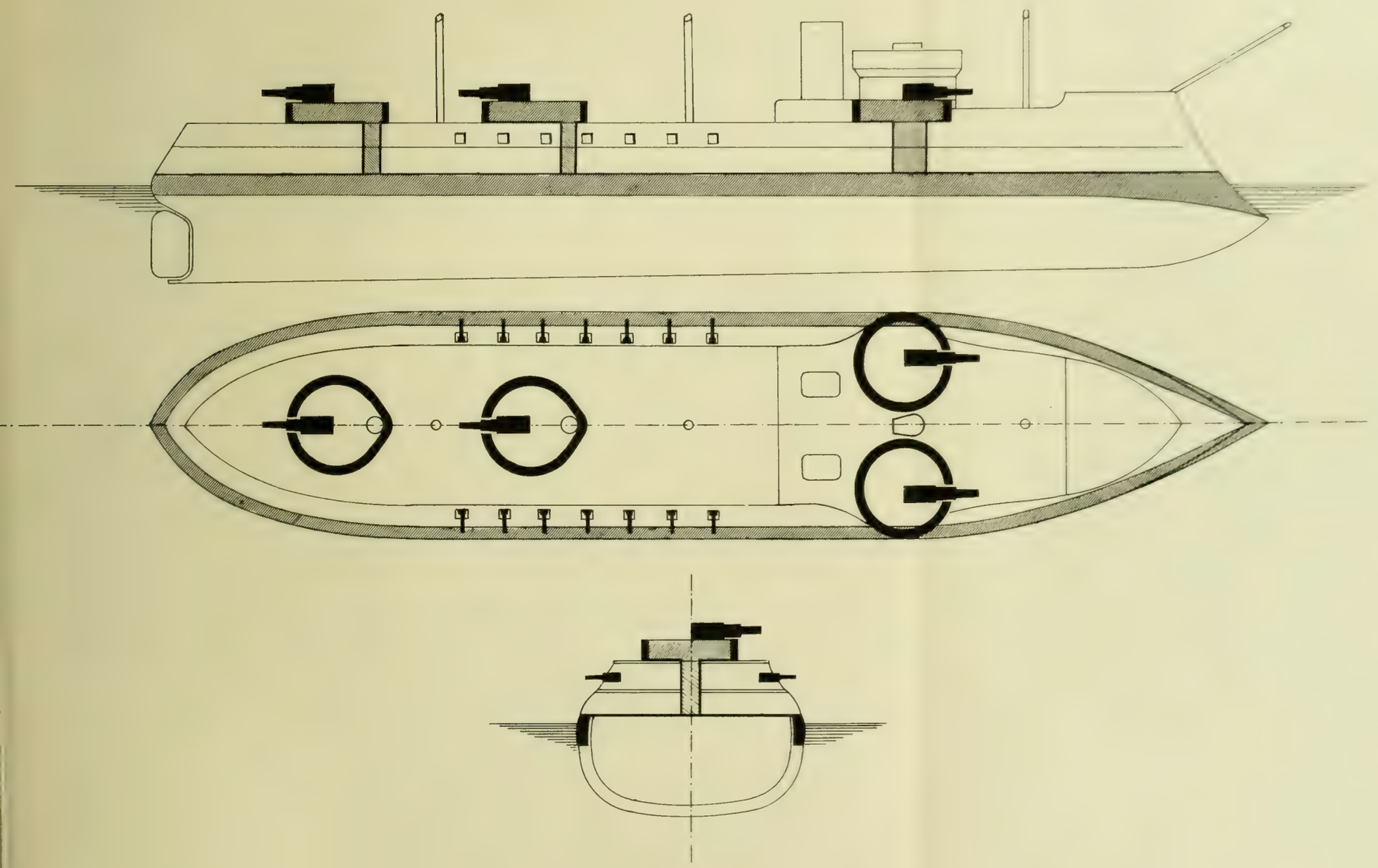
"DUILIO" AND "DANDOLO"

To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships



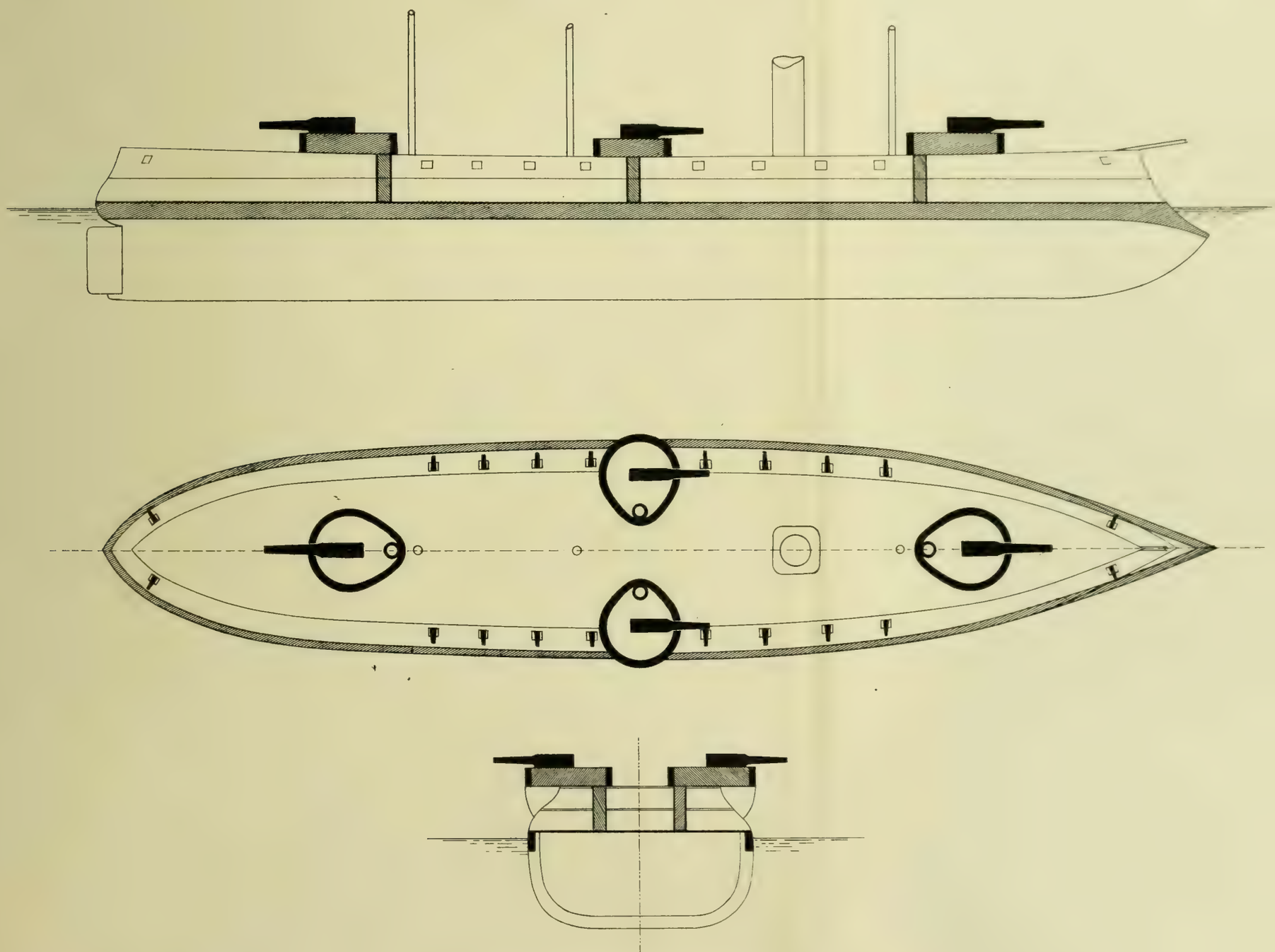
"SACHSEN" CLASS

To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.



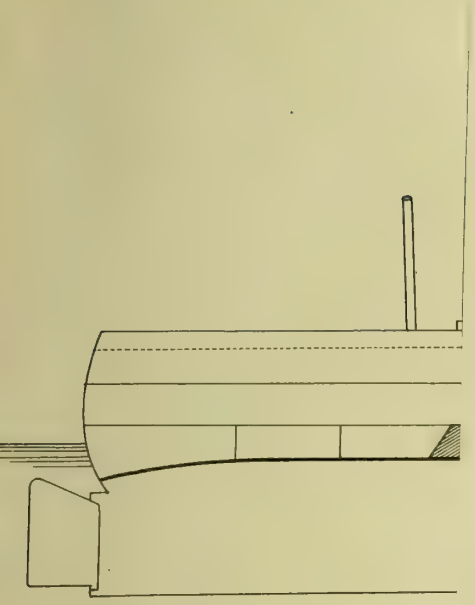
"AMIRAL DUPERRÉ."

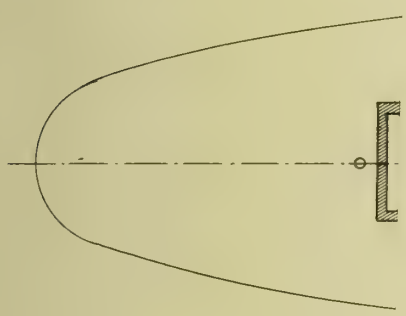
To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships



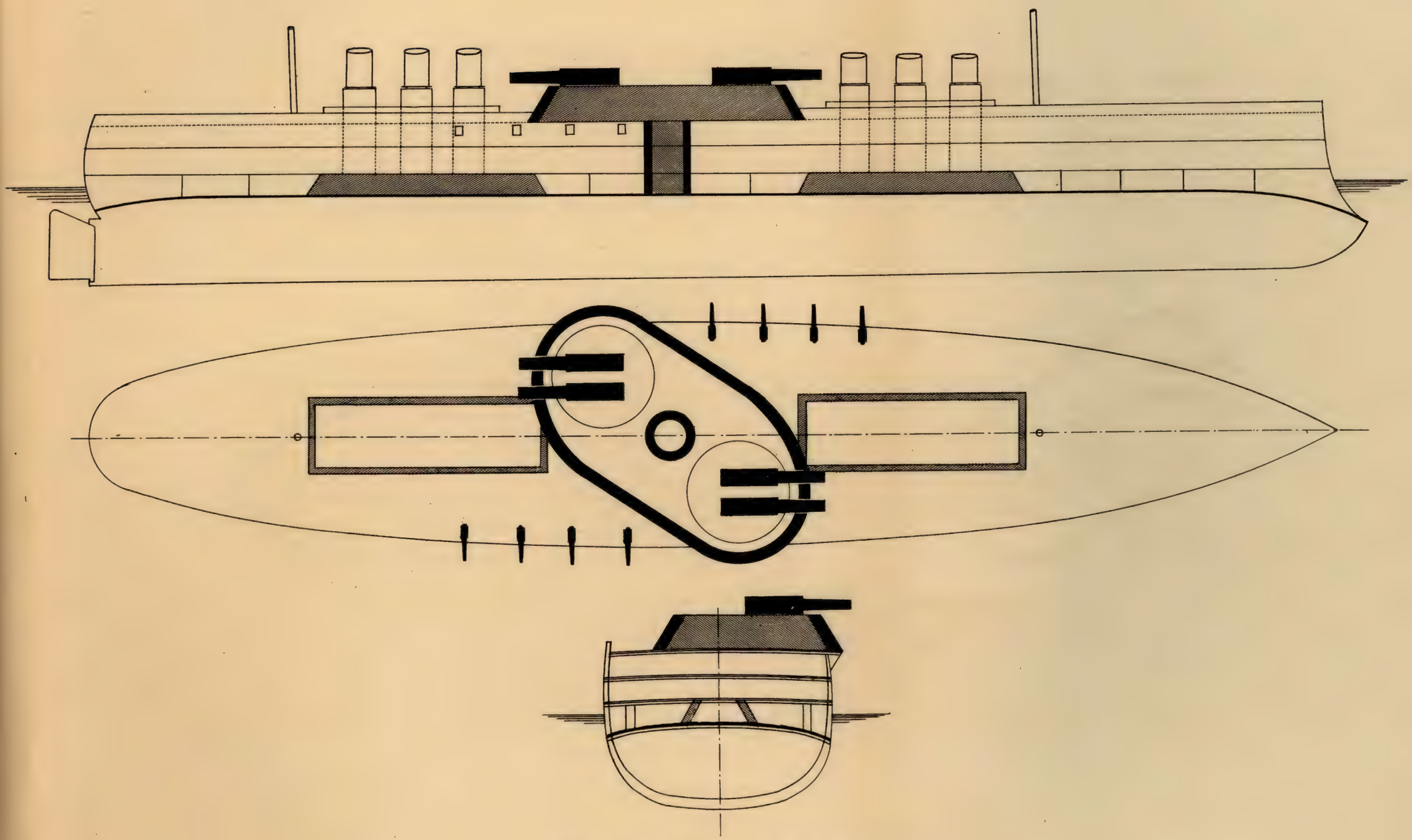
"MAGENTA" CLASS.

To



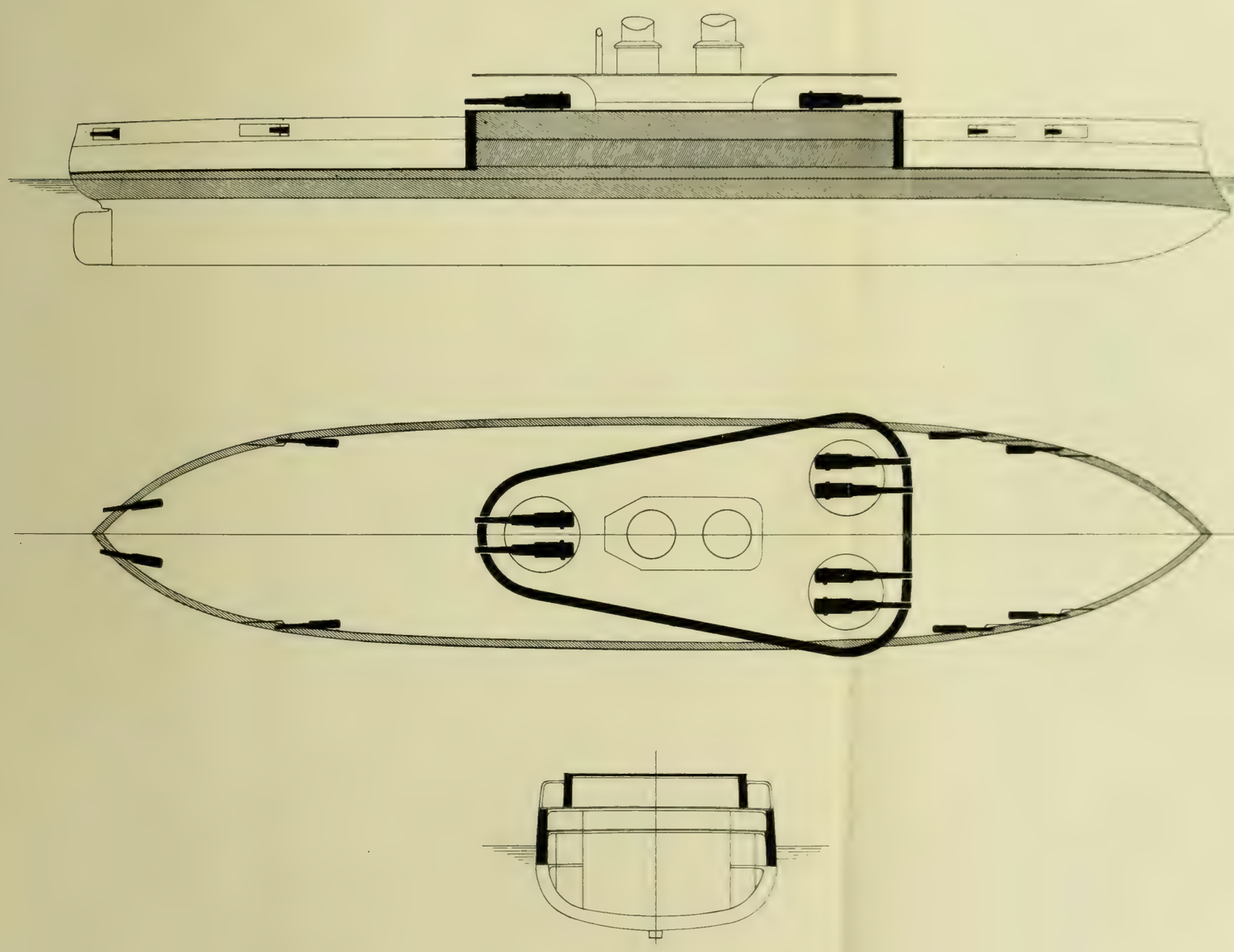


To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.



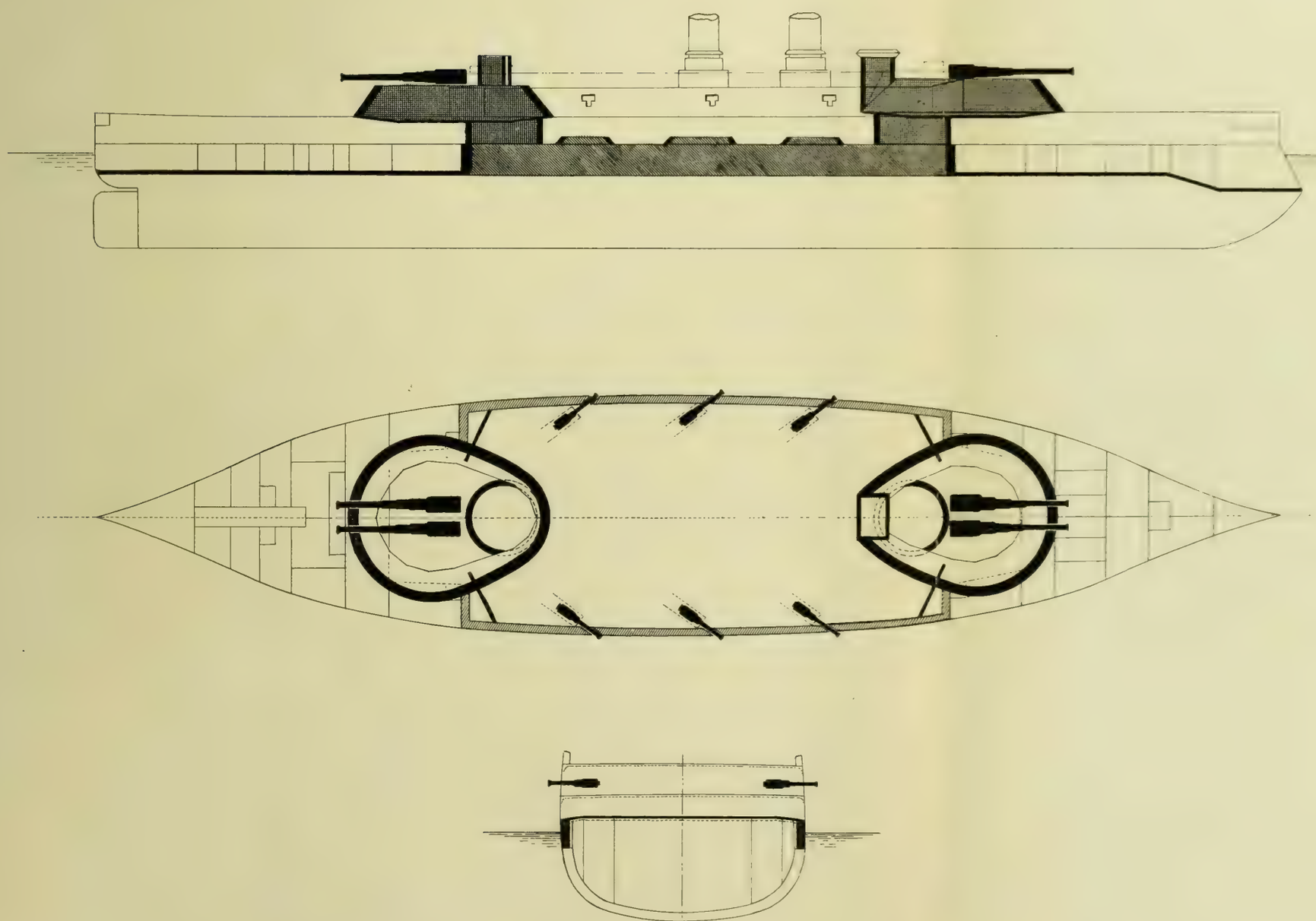
"ITALIA AND LEPANTO"

To Illustrate Mr W. H. White's Paper on the Designs for the New First-class Battle Ships



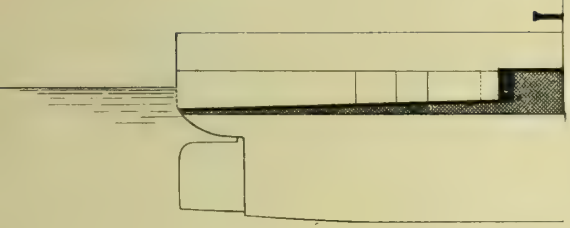
"SINOPE" CLASS

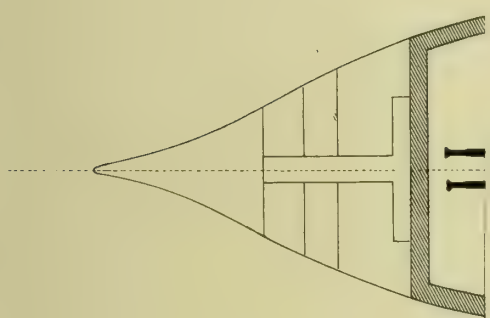
To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships



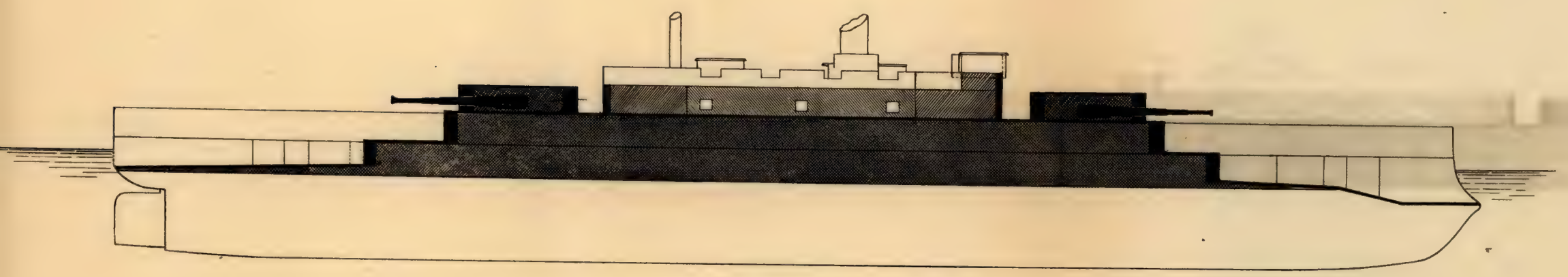
"COLLINGWOOD"

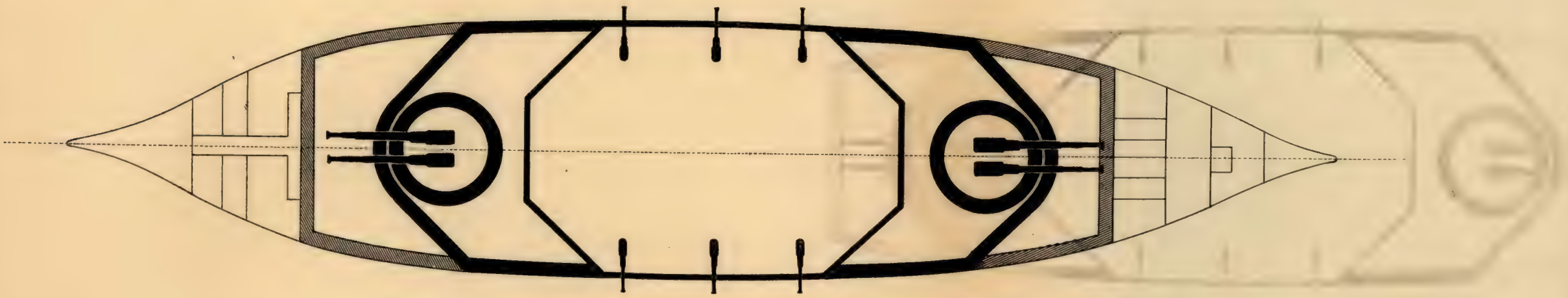
To Illustra

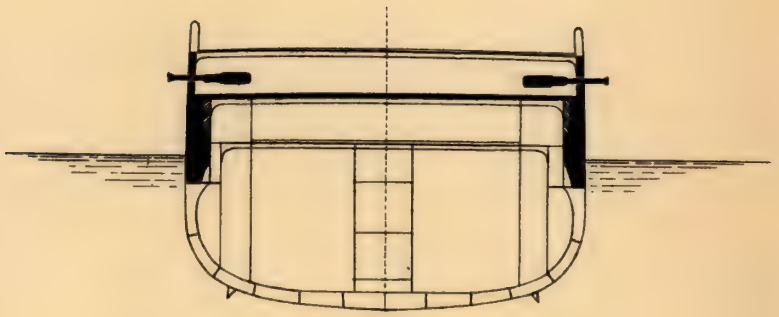




To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.

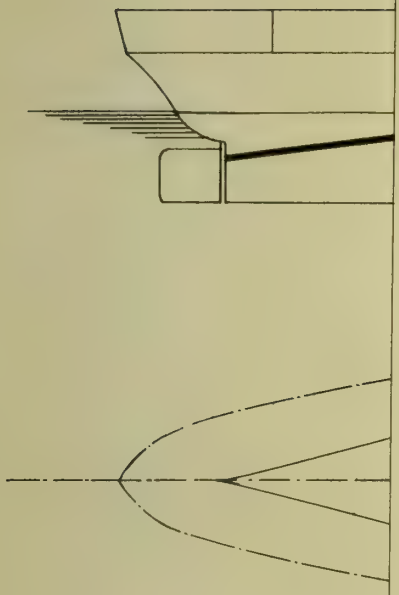




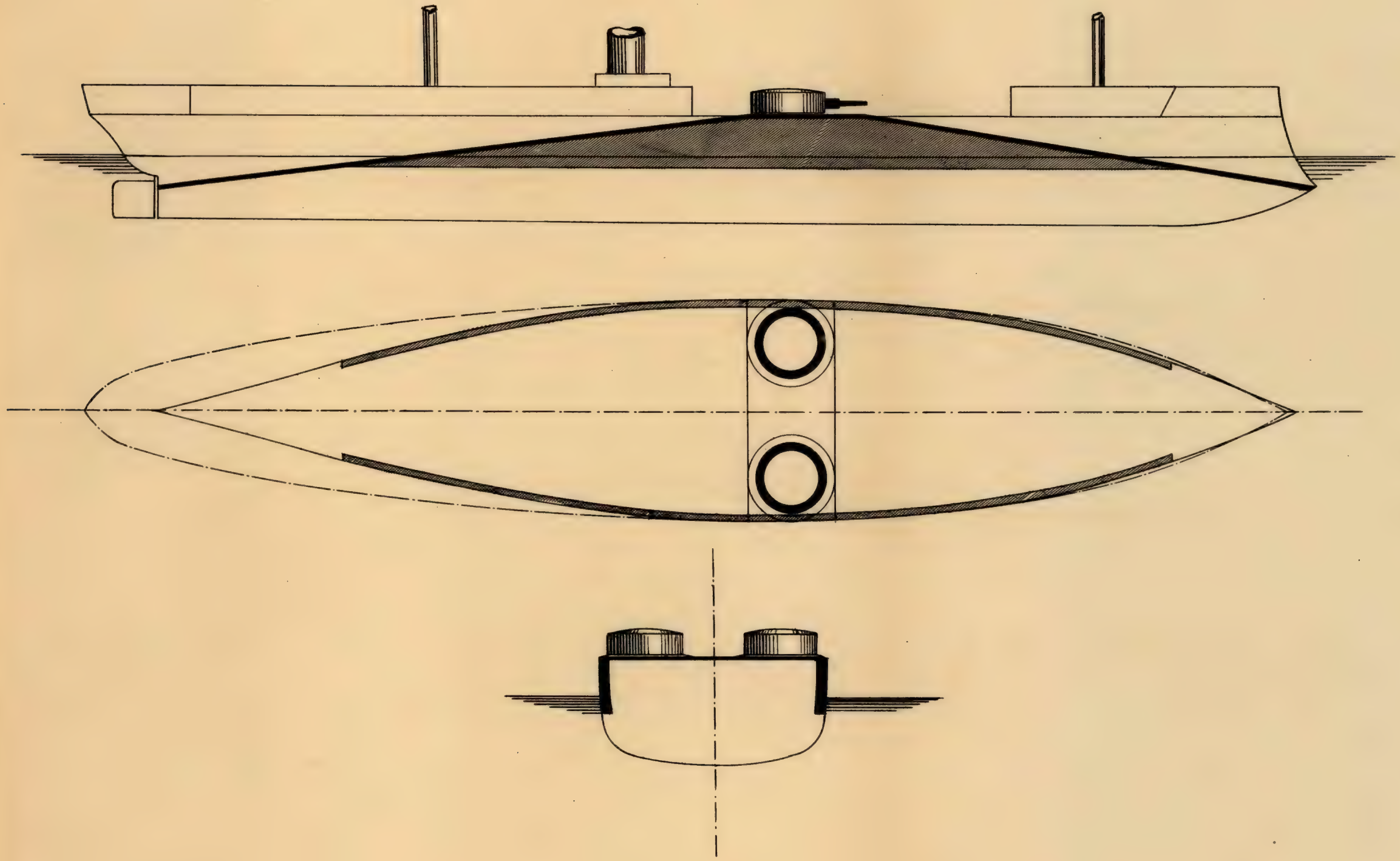


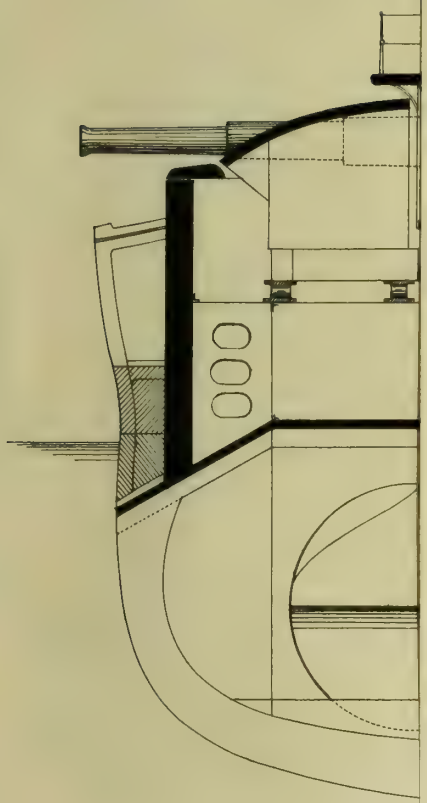
"NILE" AND "TRAFALGAR"

T



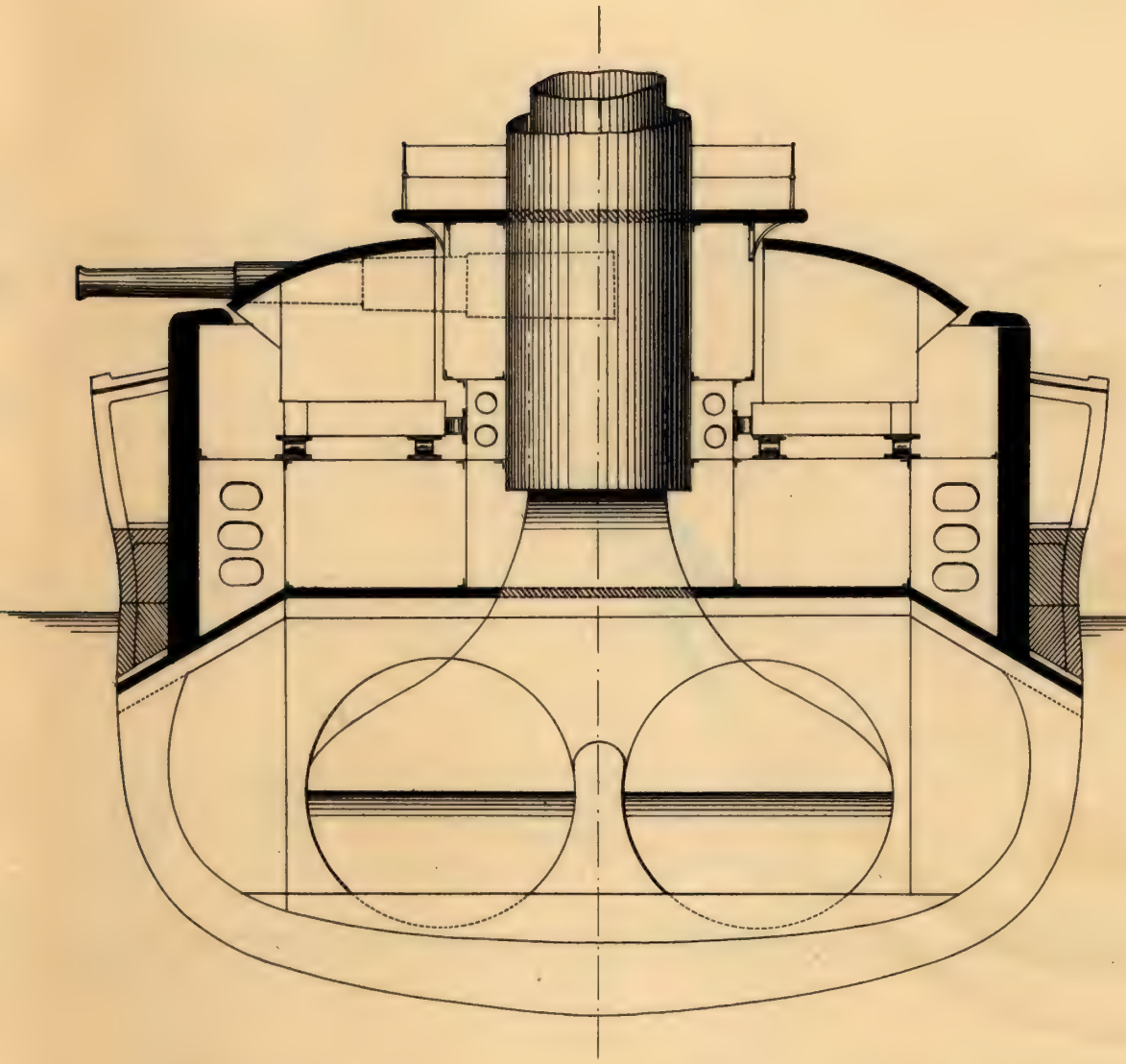
To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.

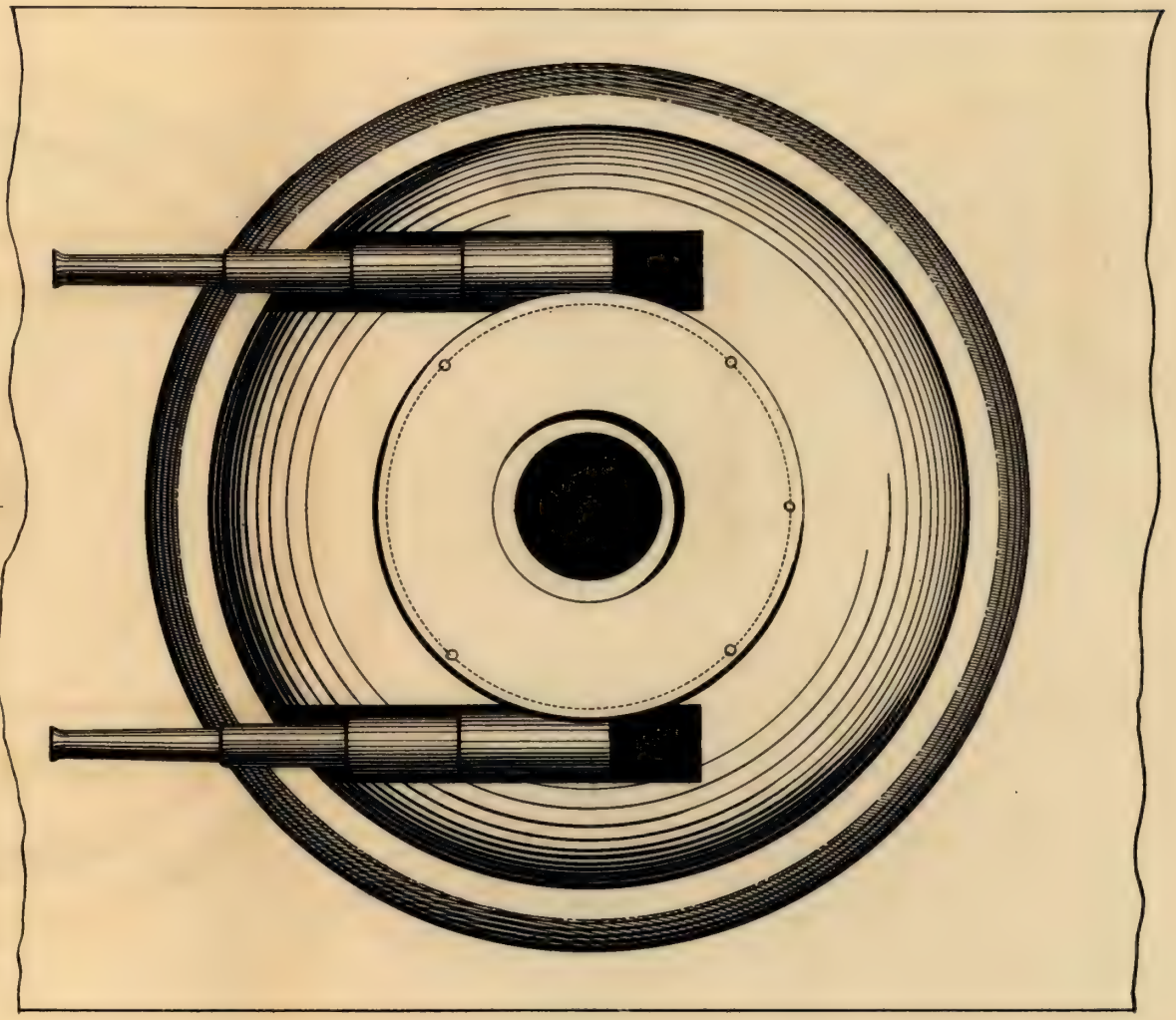




The portion below
sketch in patent

To Illustrate Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.





The portion below the protective deck has been added to the sketch in patent specification for the purposes of the diagram.

To Illustrate Sir E. J. Reed's Remarks on Mr. W. H. White's Paper on the Designs for the New First-class Battle Ships.

FIG. 1.

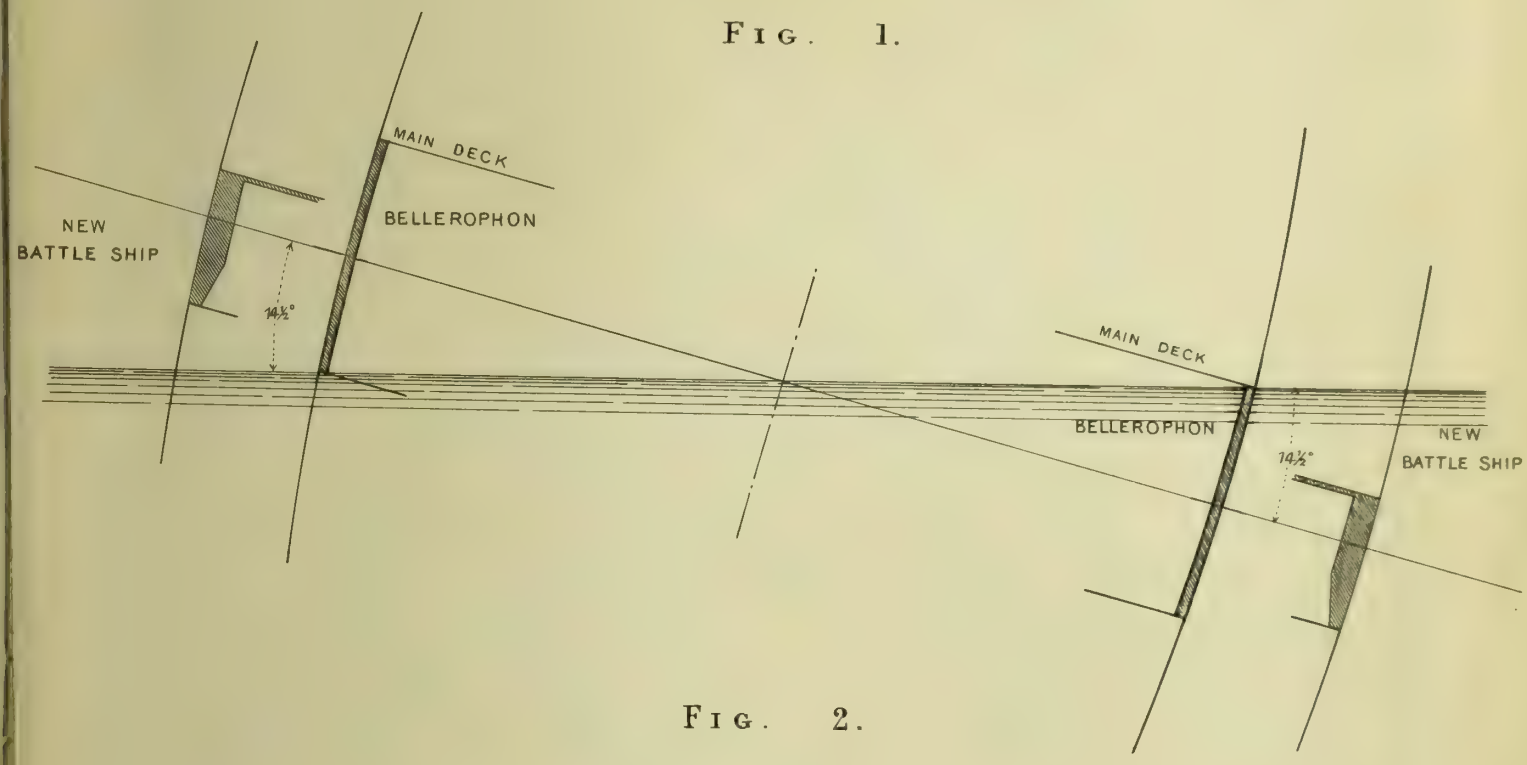
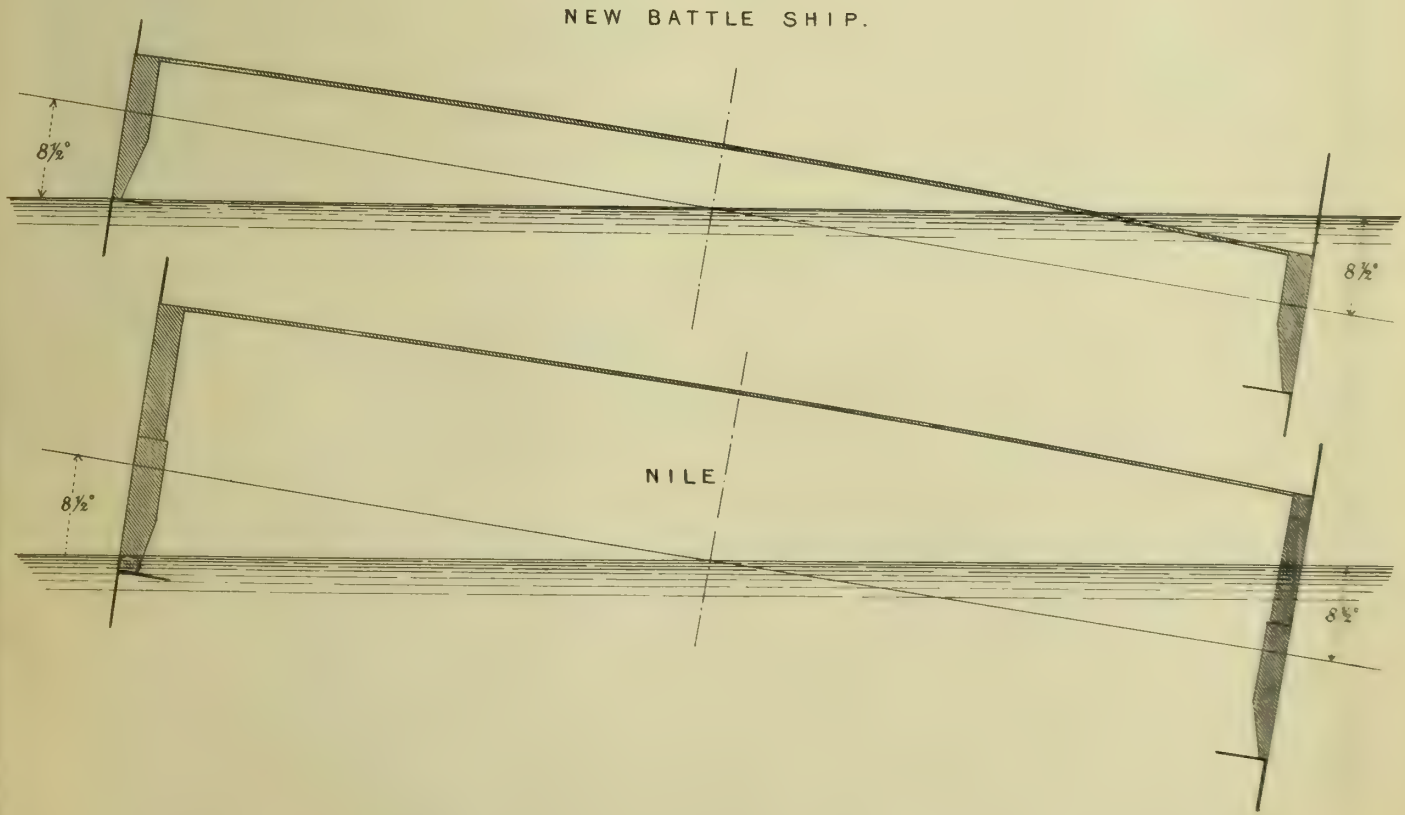
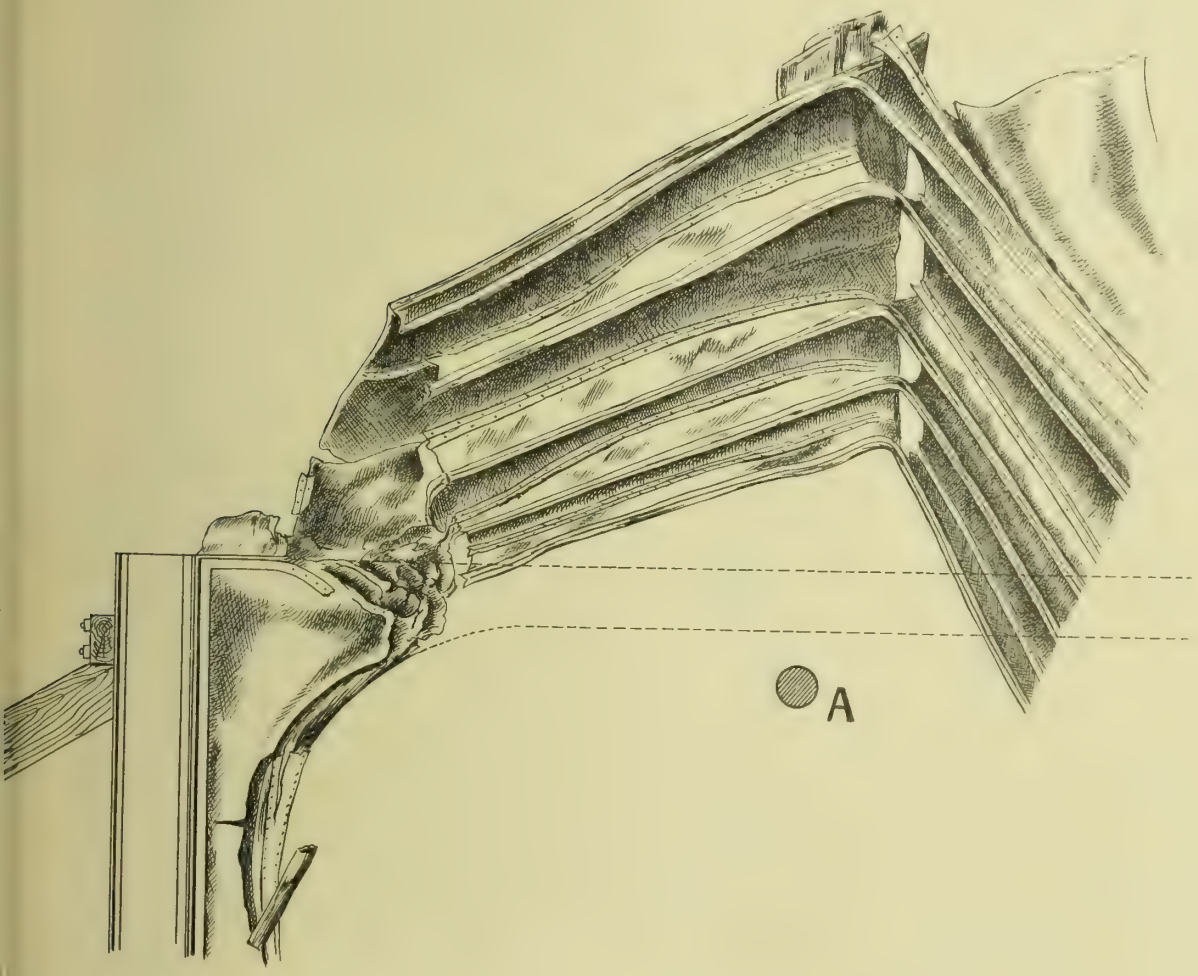


FIG. 2.



To Illustrate Sir Nathaniel Barnaby's Paper on the Protection of Buoyancy and Stability in Ships.



80 lbs of gun cotton exploded under a deck at A.

Fig

Fig

To Illustrate Mr. P. Watts' Paper on the Italian Cruiser "Piemonte."

FIG. 1. *Profile.*

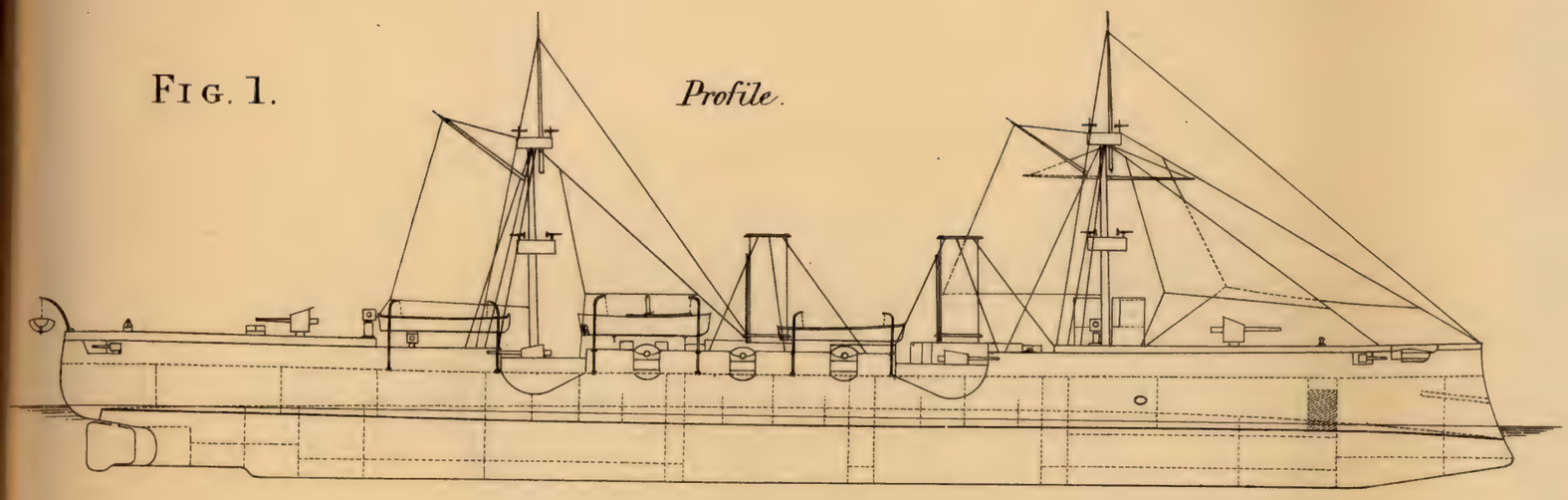


FIG. 3. *Midship Section.*

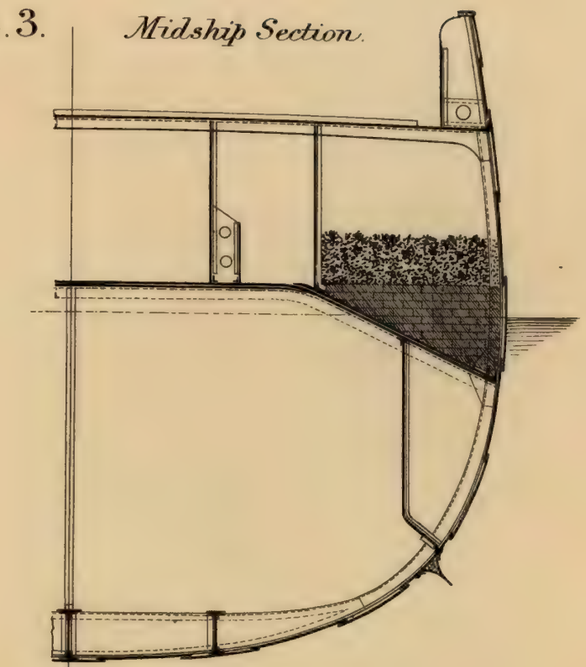


FIG. 2. *Plan of weather decks.*

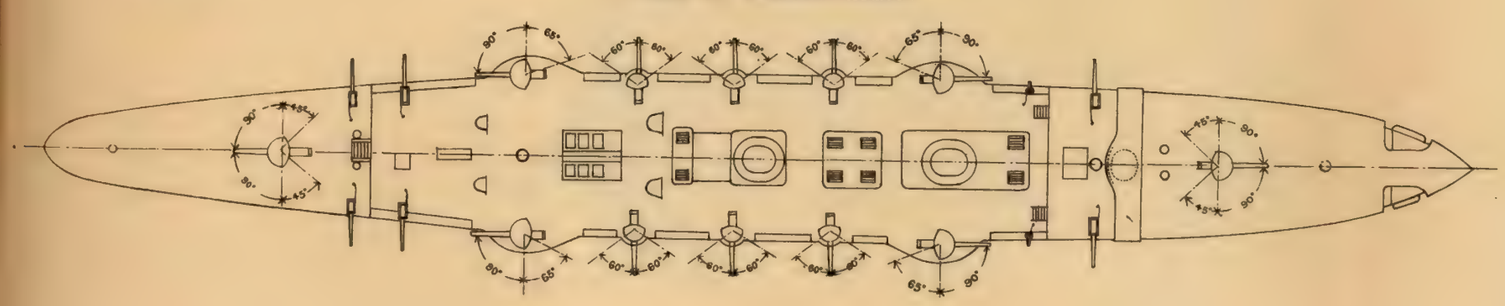


FIG. 4.

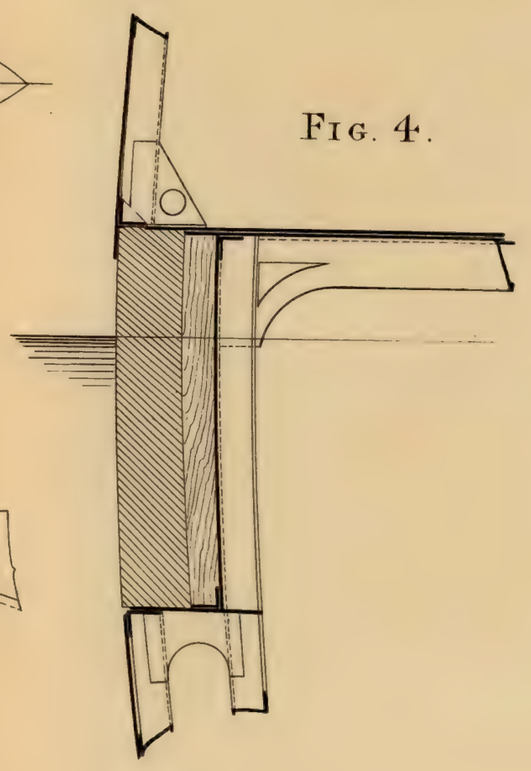


FIG. 5.

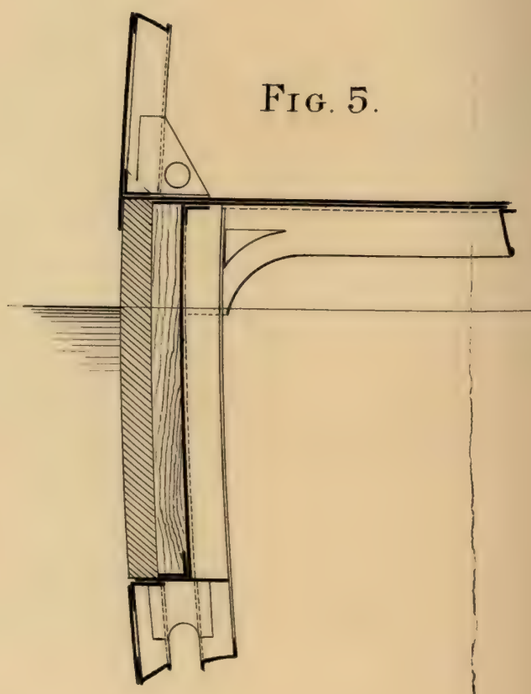
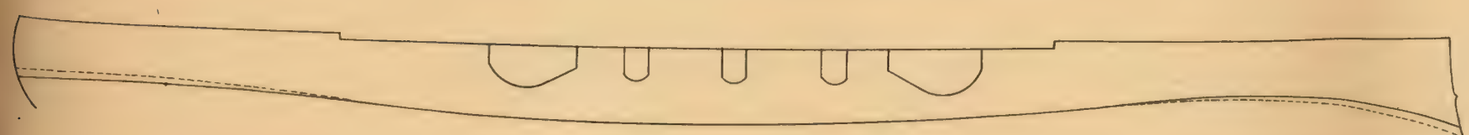
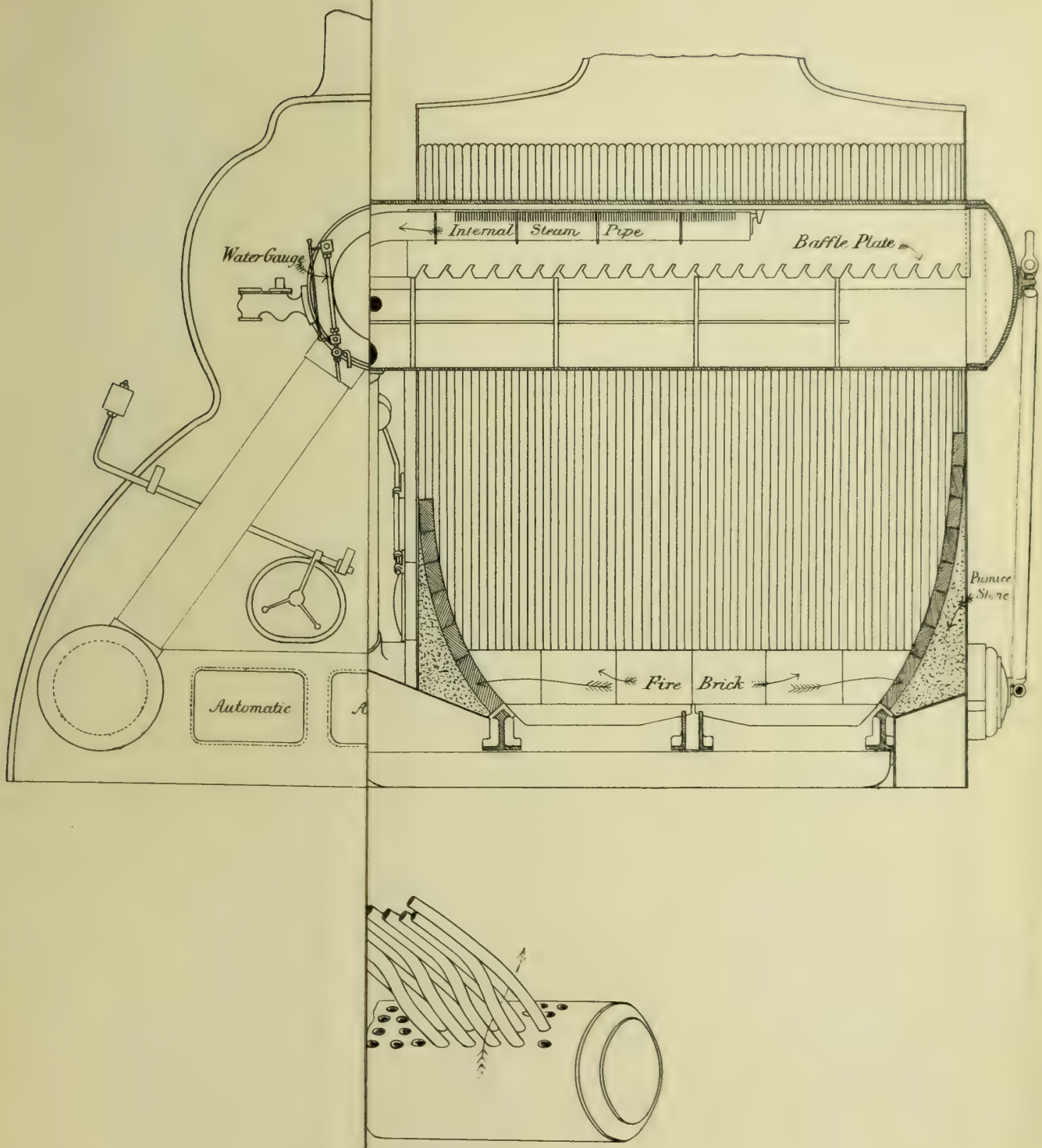


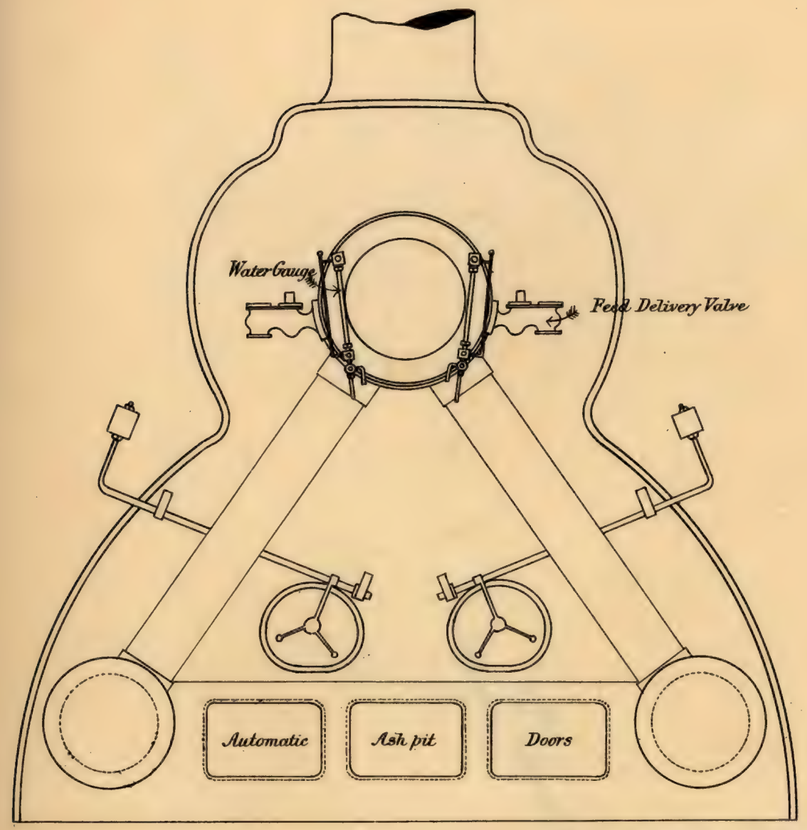
FIG. 6. *Profile of waves against side at 20 and 21½ knots.*

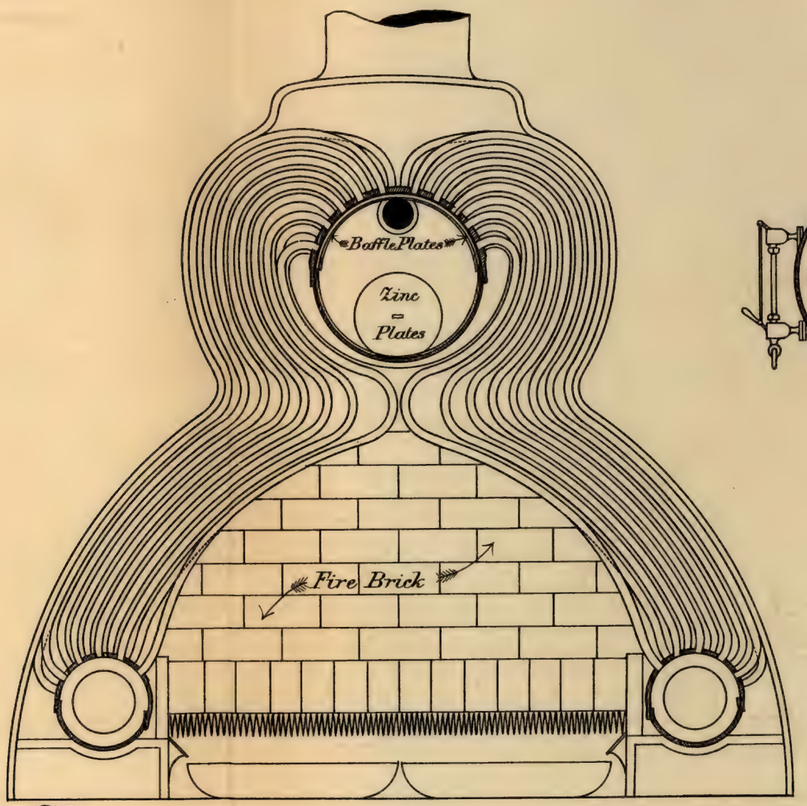


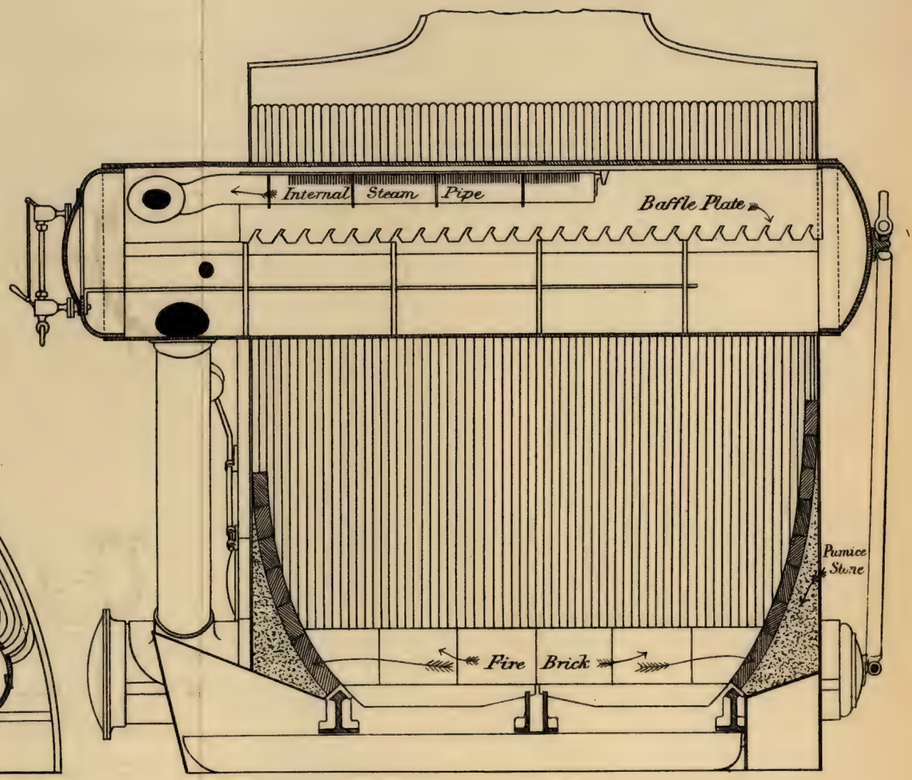

Internal Steam Pipe
Baffle Plate
Water Gauge
Pumice Stone
Fire Brick
Automatic

To Illustrate Mr. J. I. Thornycroft's Paper on Water Tube Boilers for War Ships.

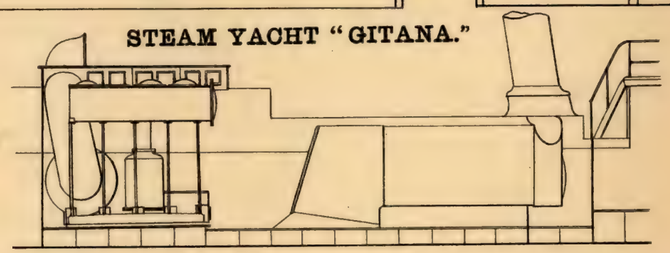
THE "THORNYCROFT" WATER TUBE BOILER.







STEAM YACHT "GITANA."



STEAM YACHT "GITANA"

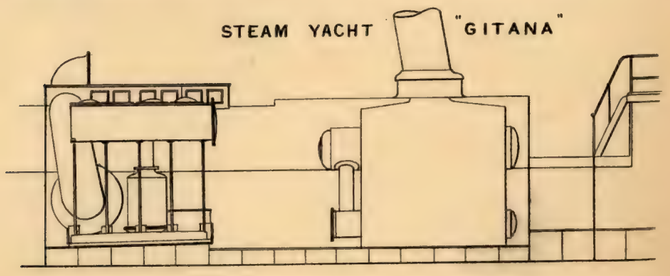
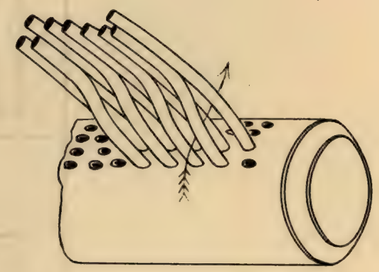


Diagram illustrating saving in length of machinery space and increase of heating surface effected by the substitution of Thornycroft's Patent Water-tube Boiler for the locomotive type.

	Old Boiler.	New Boiler.
Grate Surface, in square feet....	16·2	22·7
Heating Surface, firebox	51·87	75·0
Do. tubes ..	653·43	1335
Do. total	705·3	1410
Weight of Boiler, in tons	6·25	5·9
Weight of Water, in tons	1·87	1·35
Total weight....	8·12	7·25



ngs.

ation.

G. 3.

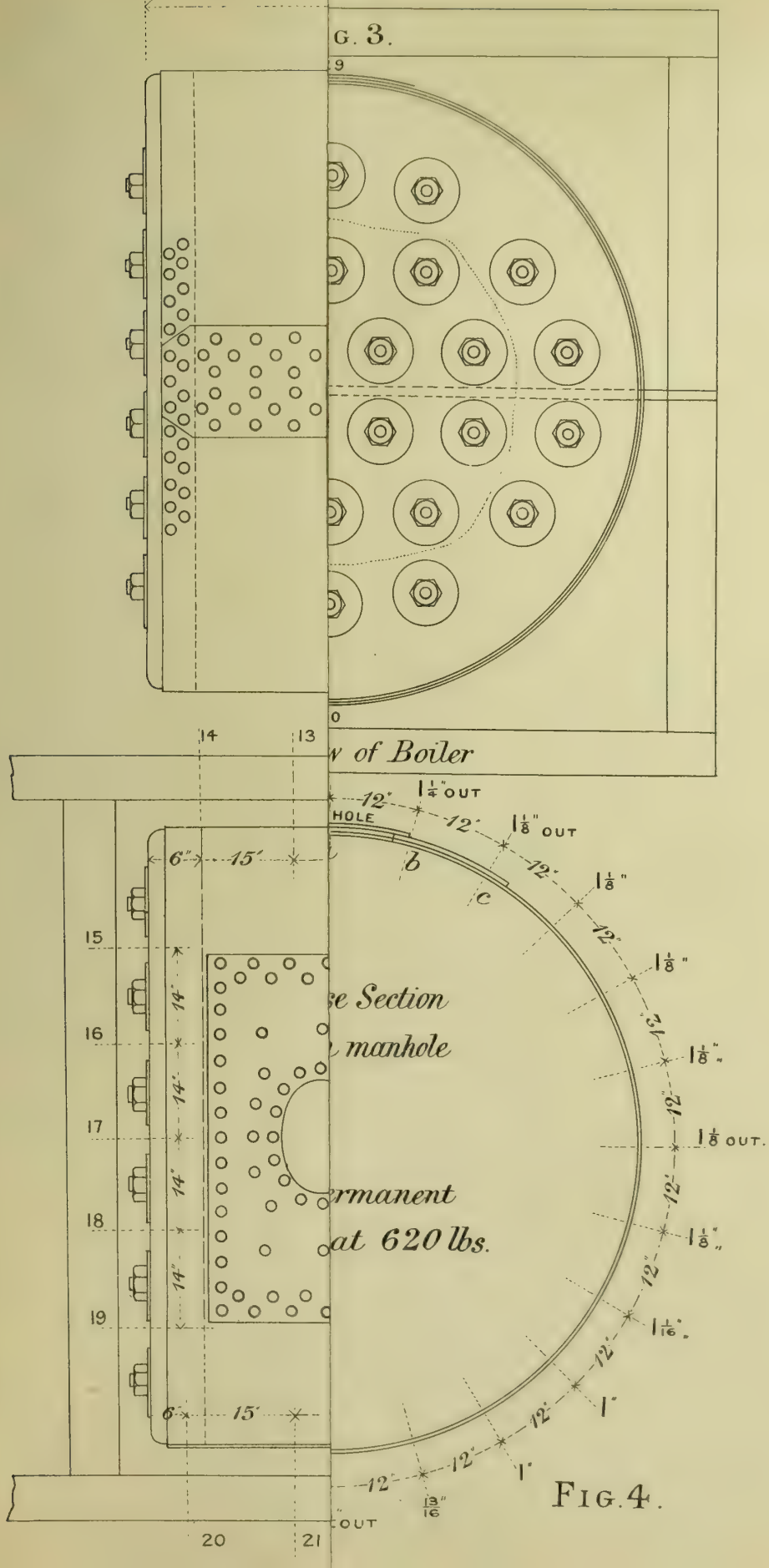
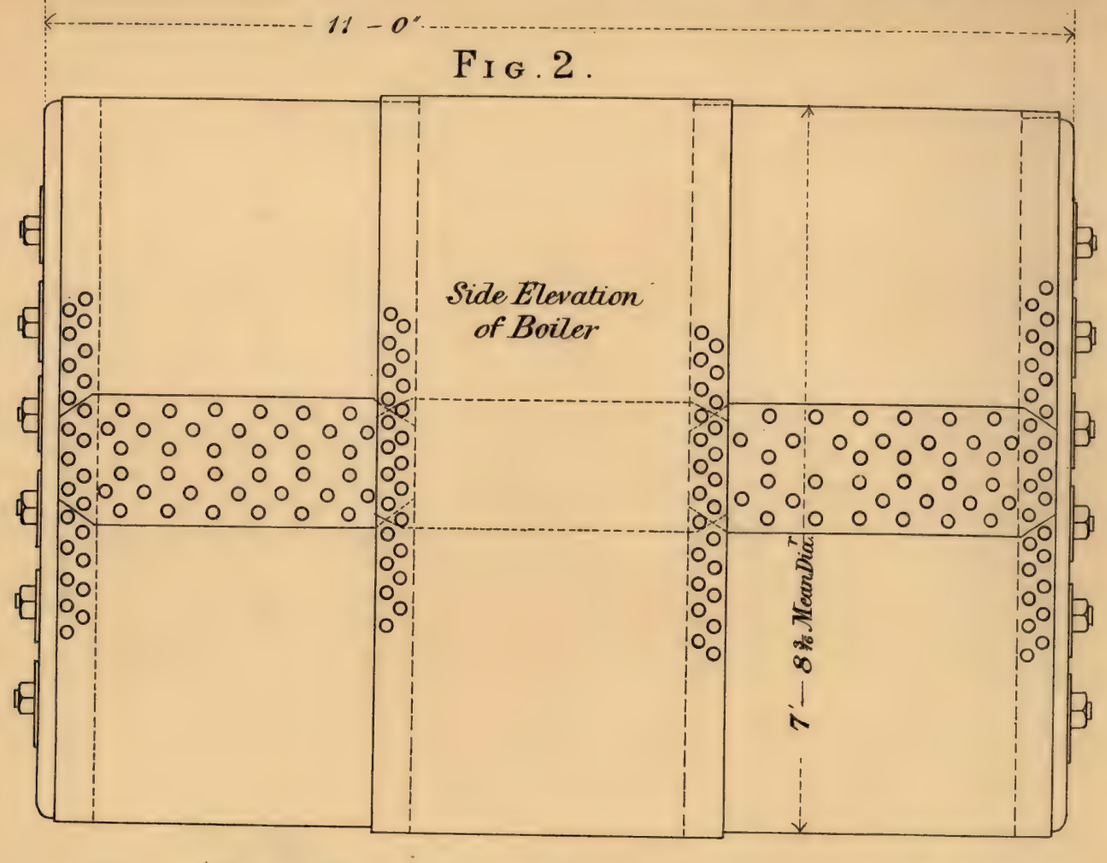


FIG. 4.

To Illustrate Mr. John Scott's Paper on Experiments on Bursting a Boiler made to Admiralty Scantlings.

FIG. 2.



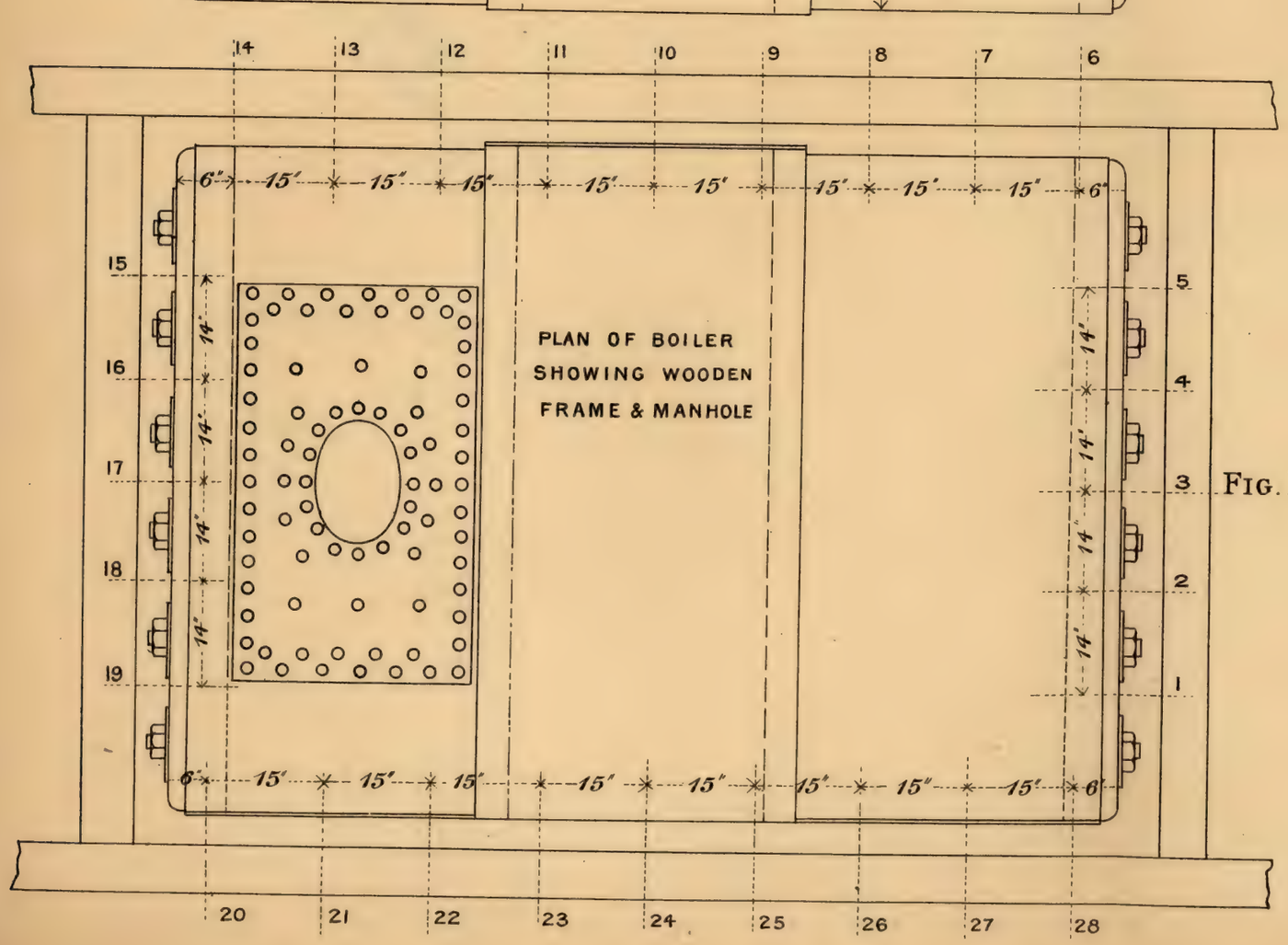
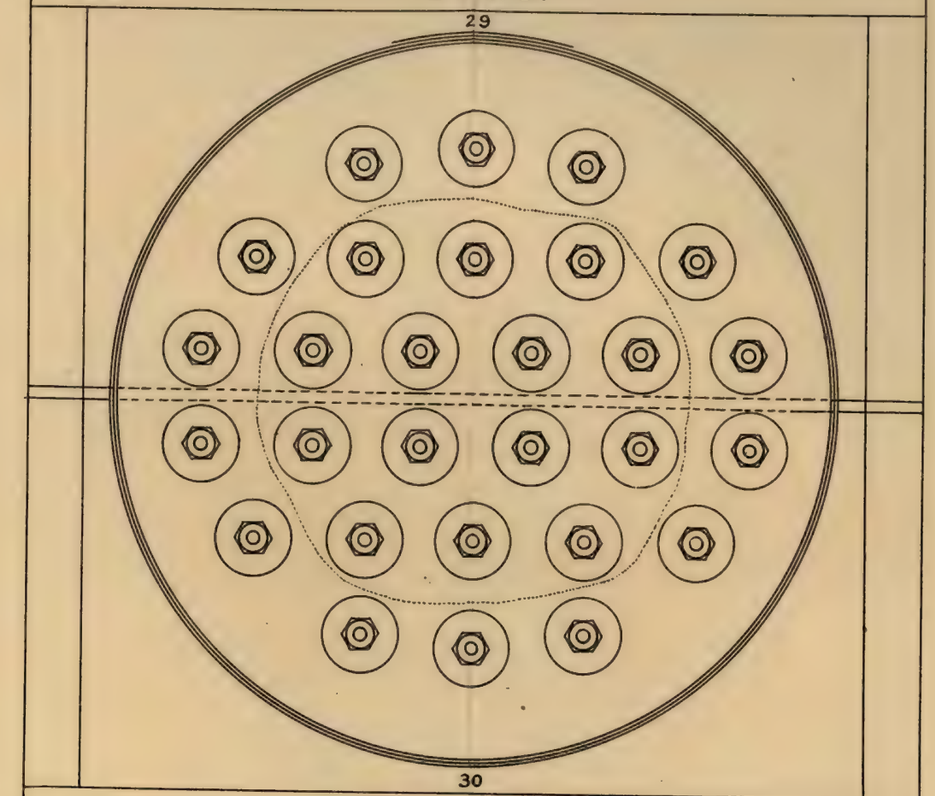


FIG. 1.

FIG. 3.



End view of Boiler

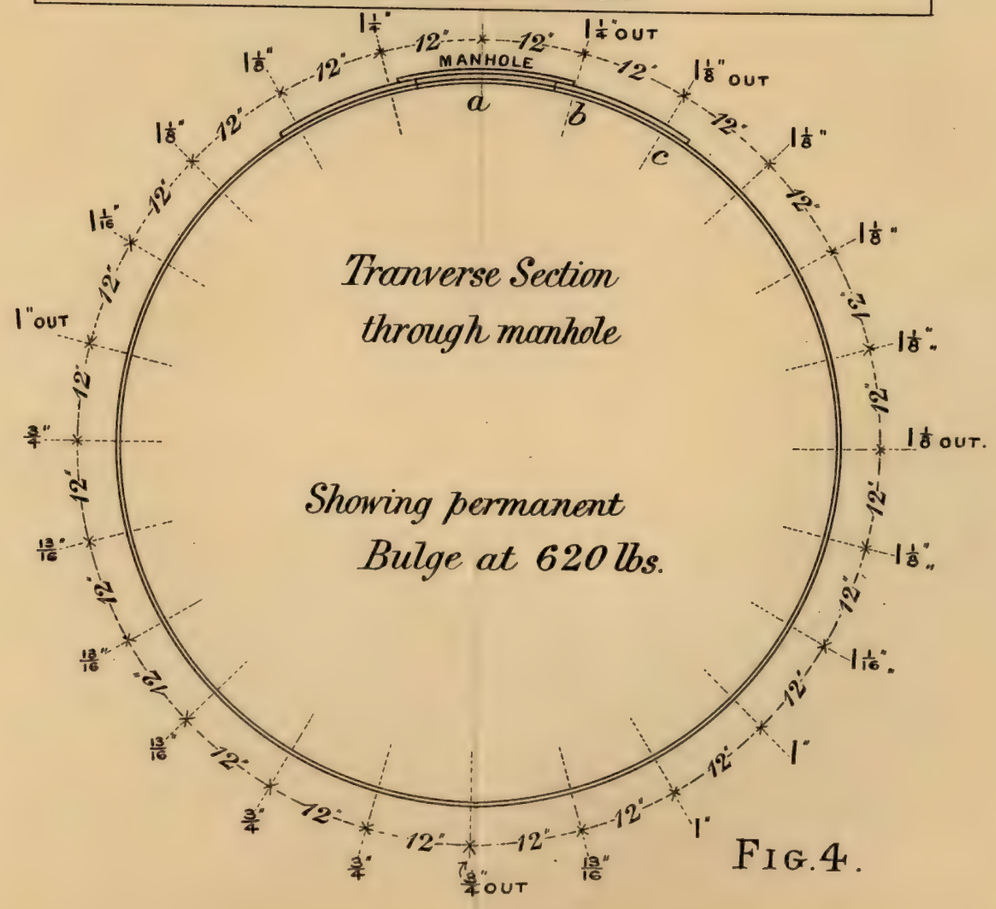
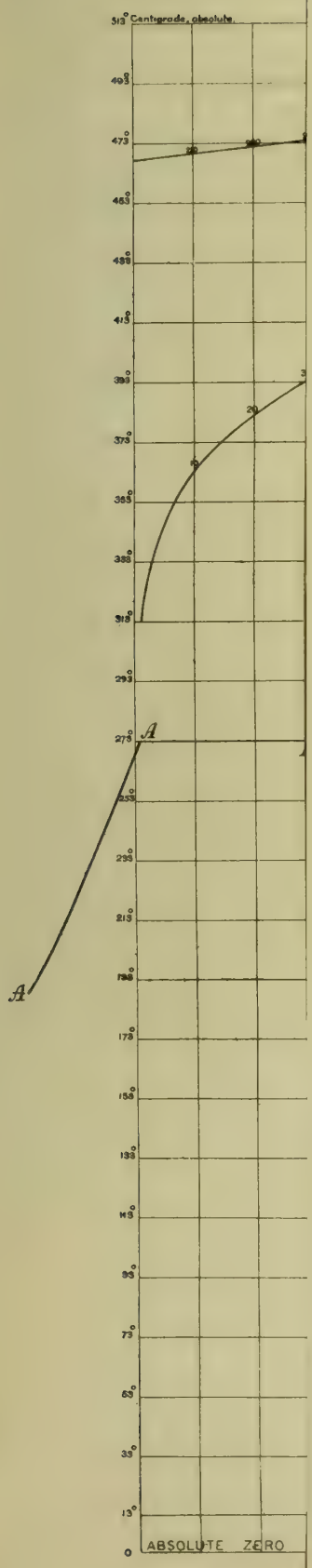
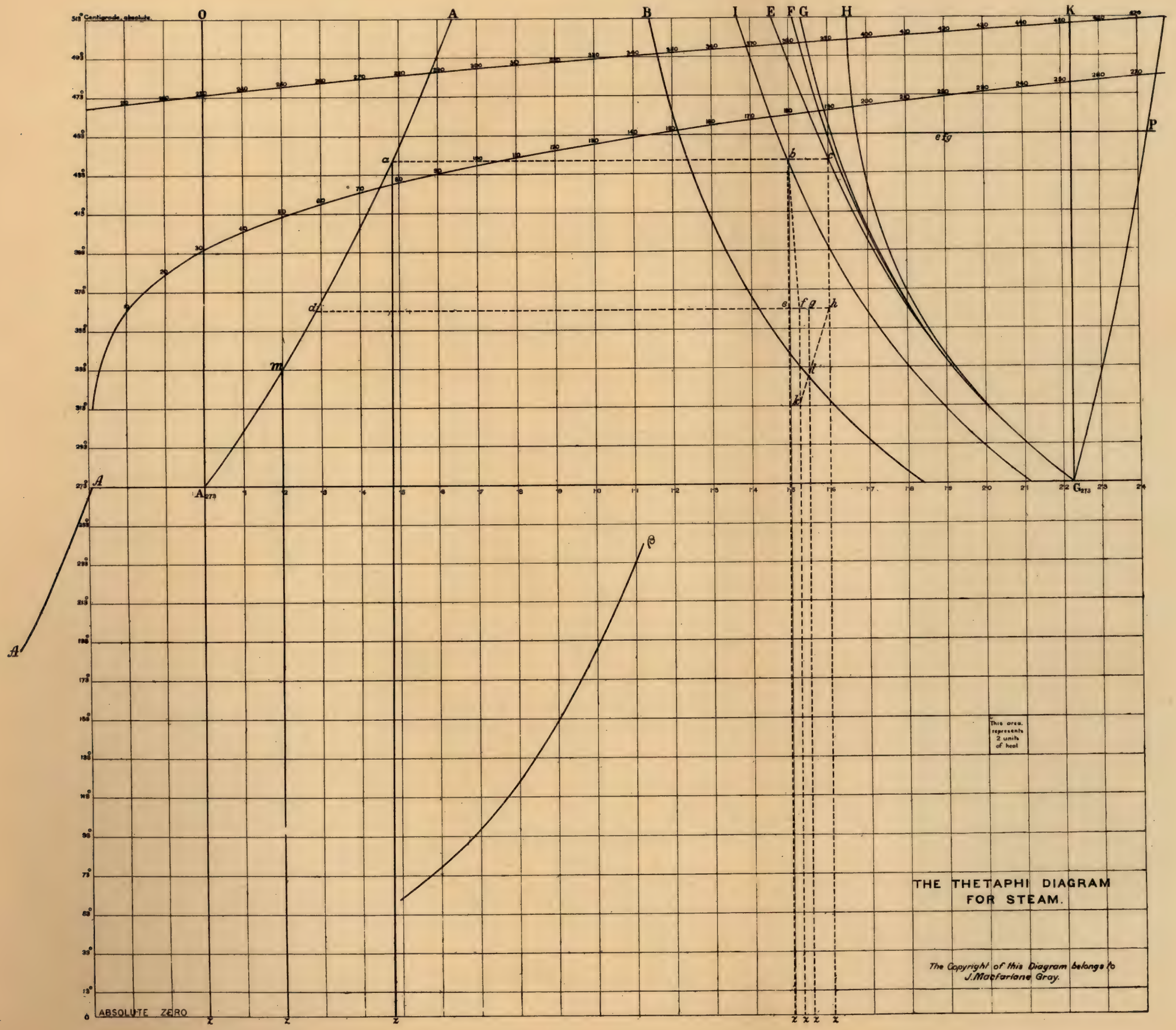


FIG. 4.

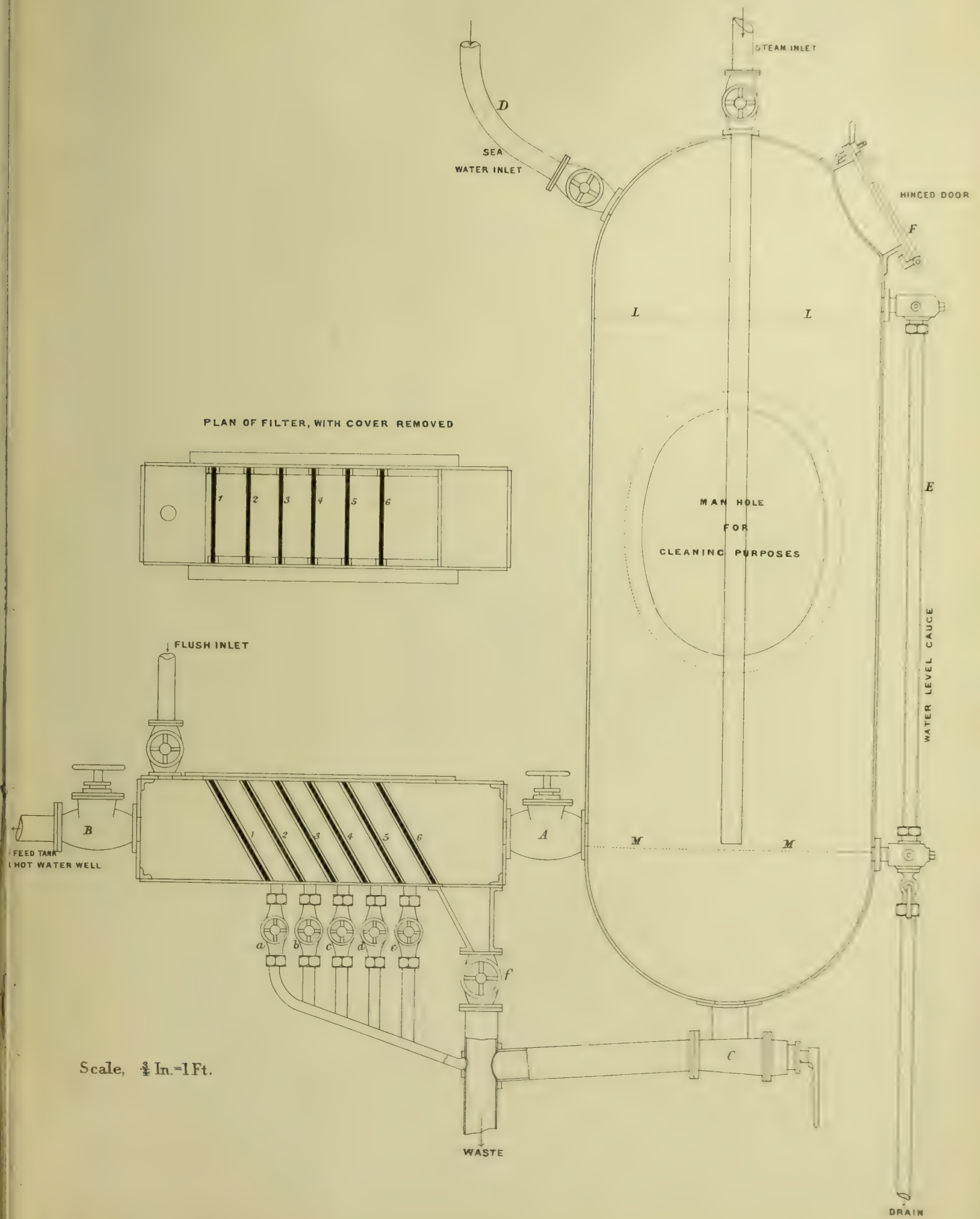
T



To Illustrate Mr. J. Macfarlane Gray's Paper on the Ether-Pressure Theory of Thermodynamics applied to Steam.



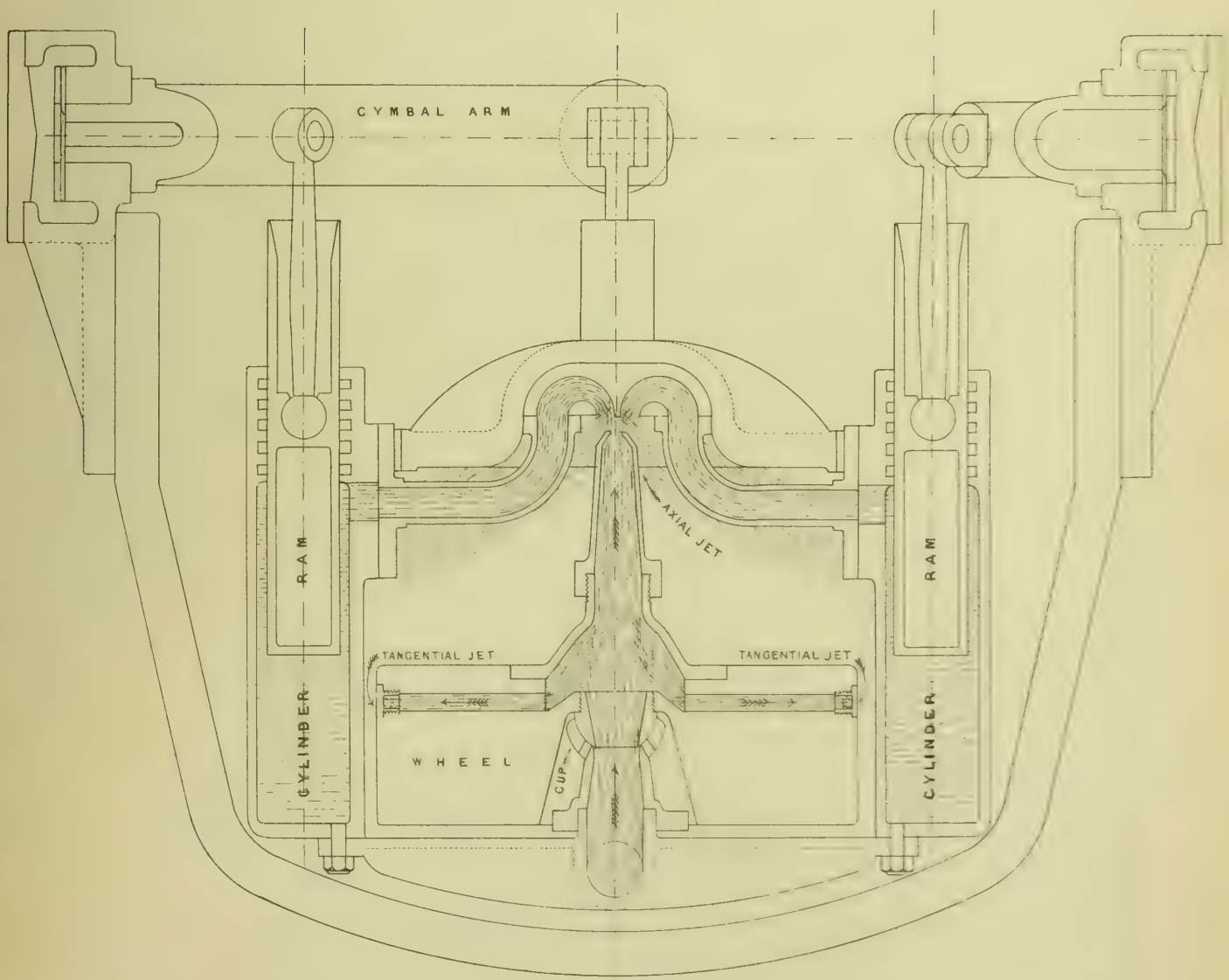
To Illustrate Professor V. B. Lewes' Paper on Marine Boiler Incrustations and their Formation.



Scale, ¾ In.=1 Ft.

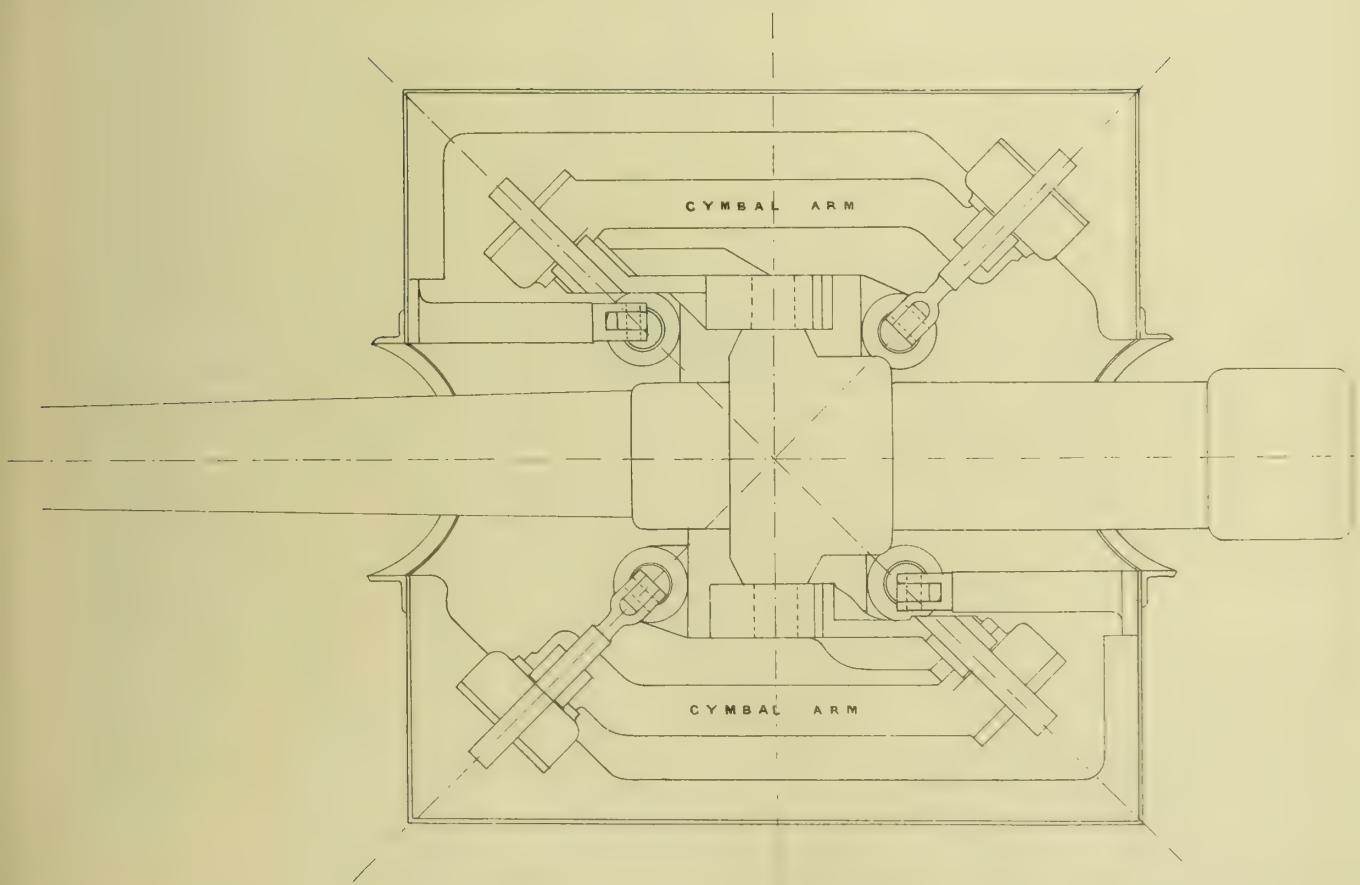
To Illustrate Mr. B. Tower's Paper on an Apparatus for Providing a Steady Platform for Guns, &c., at Sea.

FIG. 1.



To Illustrate Mr. B. Tower's Paper on an Apparatus for Providing a Steady Platform for Guns, &c., at Sea.

FIG. 2.



To Illustrate Mr. B. Tower's Paper on an Apparatus for Providing a Steady Platform for Guns, &c., at Sea.

FIG. 3.

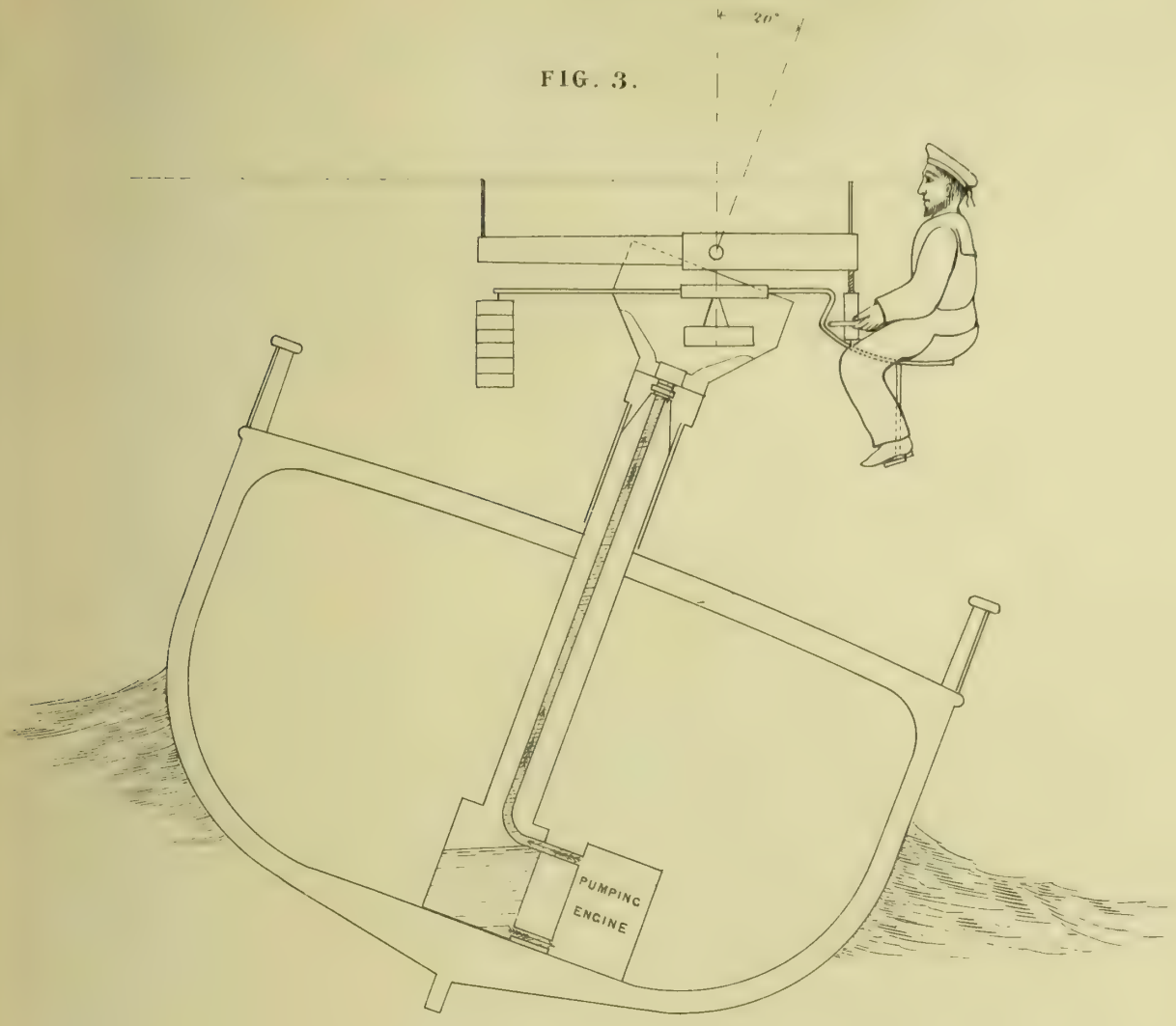
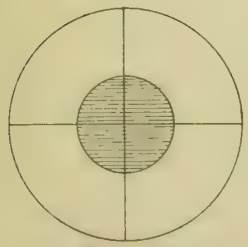


FIG. 5.



VIEW OF PORTS
SHADED CIRCLE IS A SECTION OF JET

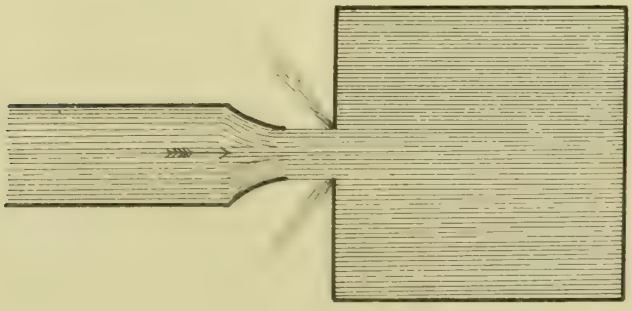
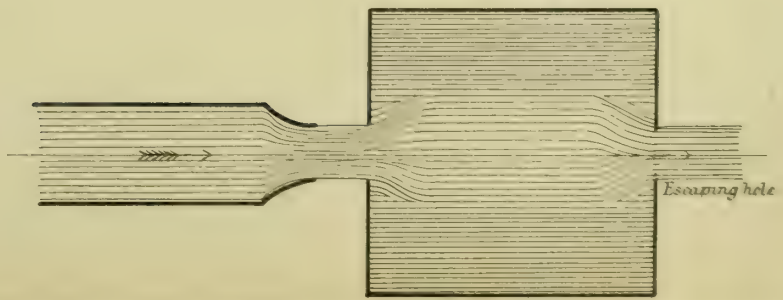


FIG. 4.



To Illustrate Mr. R. E. Froude's Paper on the Part Played in the Operations of Propulsion by Differences in Fluid Pressure.

F'

FIG. 1.

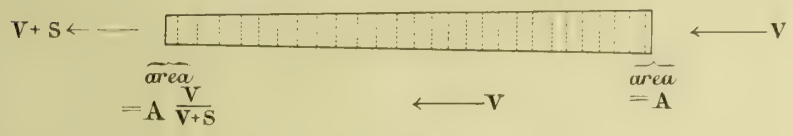


FIG. 2.

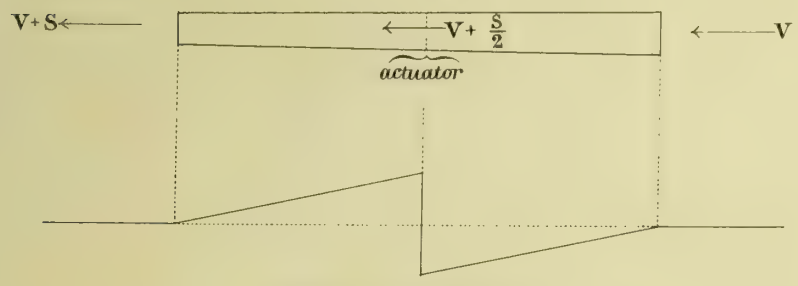


Diagram of internal pressure.

FIG. 3.

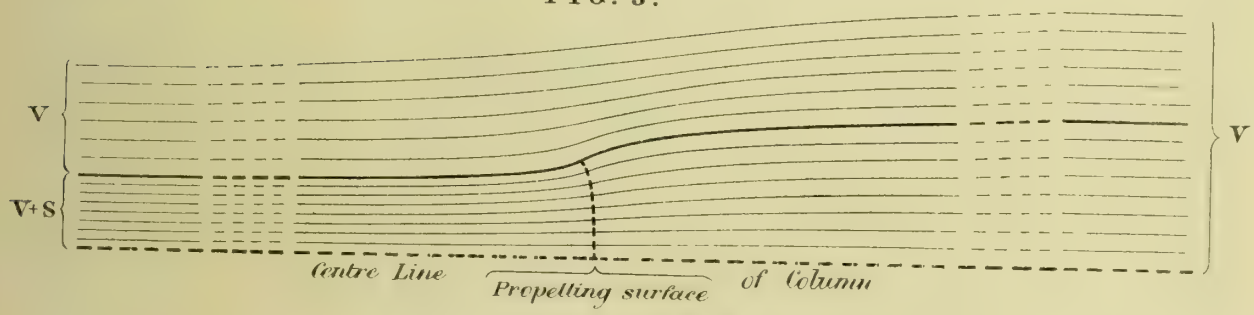
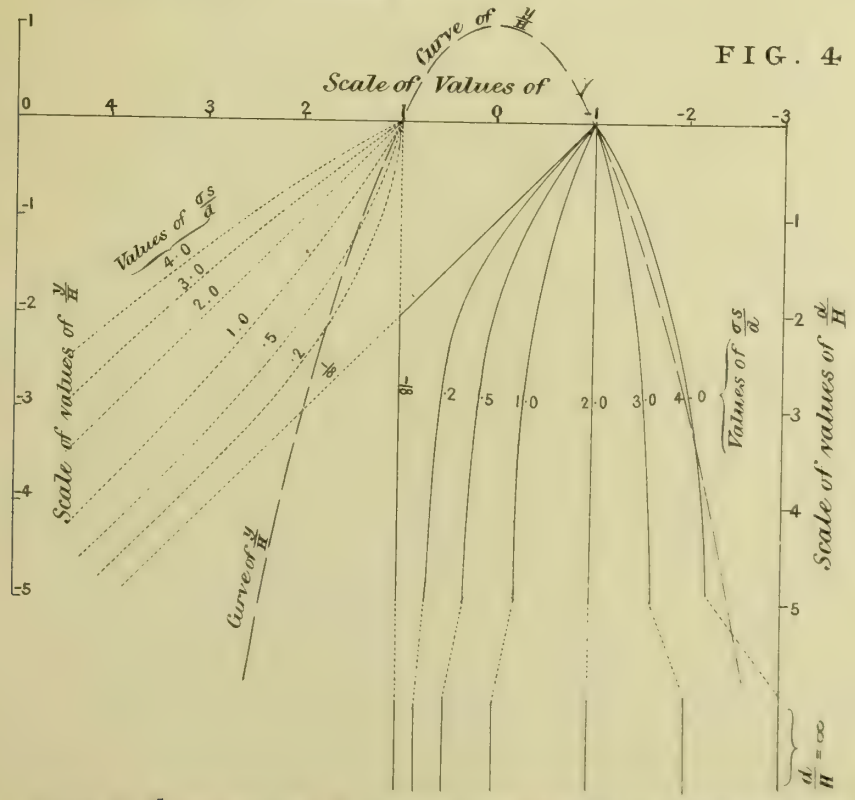


FIG. 4.



Curves of $\frac{d}{H}$ with varying γ, for the several values of $\frac{\sigma S}{d}$ figured on them.
—— Solution with γ less than = 1
·· Alternative d.° with d.° greater than d.°

To Illustrate Mr. R. E. Froude's Paper, Remarks on Professor Greenhill's Theory of the Screw Propeller.

FIG. 1.

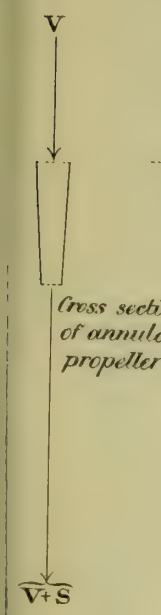


FIG. 2.

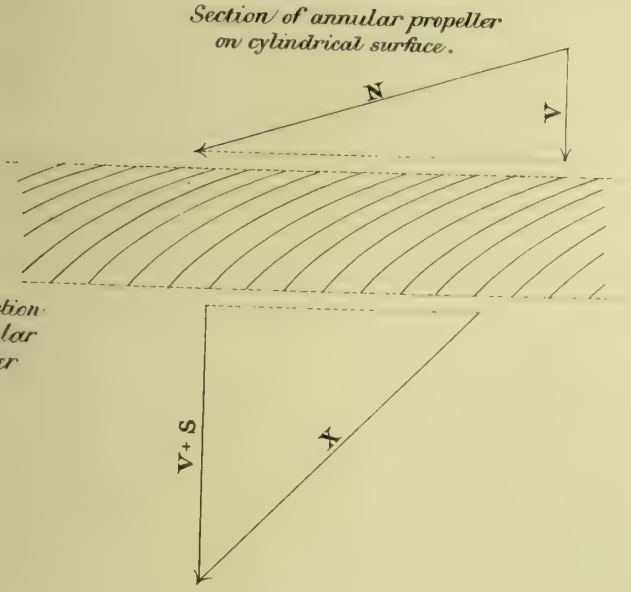


FIG. 3.

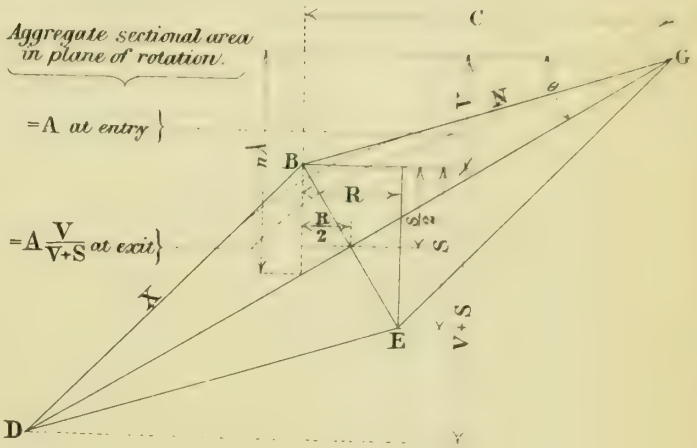


FIG. 4.

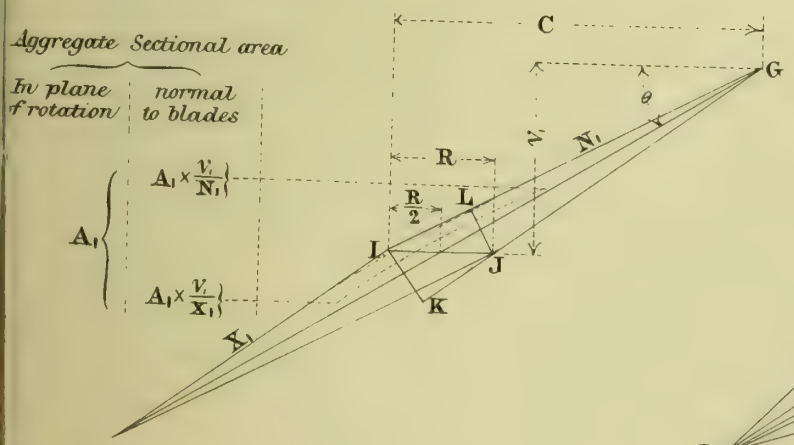
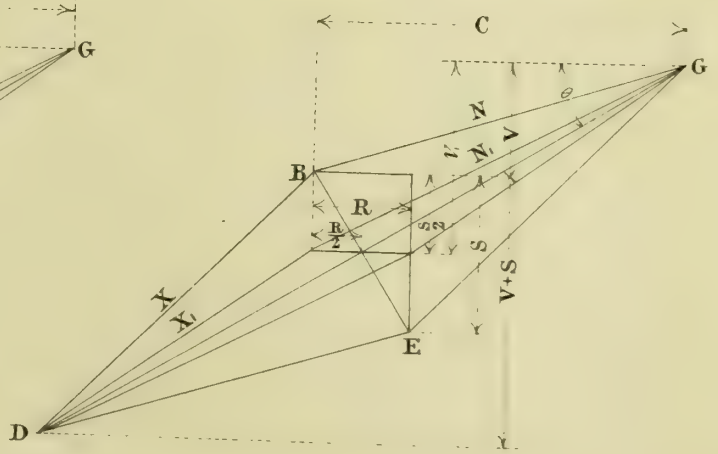


FIG. 5.



SCALE OF RIGHTING ARM

To Illustrate Professor P. Jenkins' Paper on the Connection between the Curve of Stability and the Metacentric Curve or Locus of Pro-Matacentres.

FIG. 1.

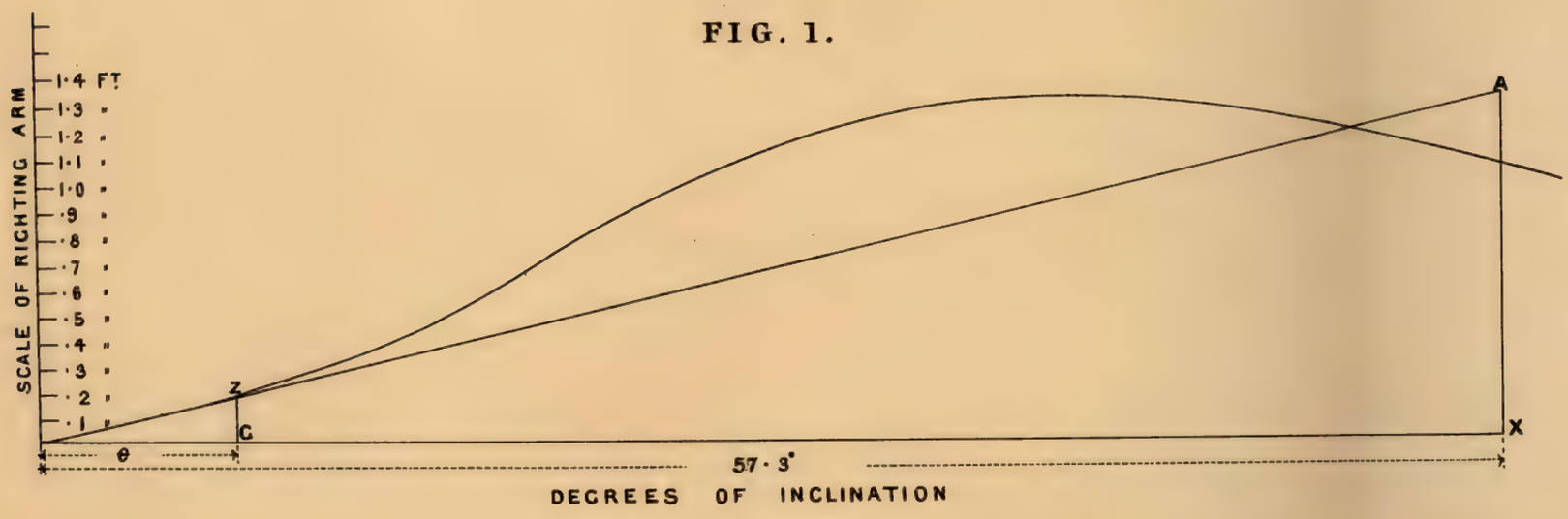


FIG. 2.

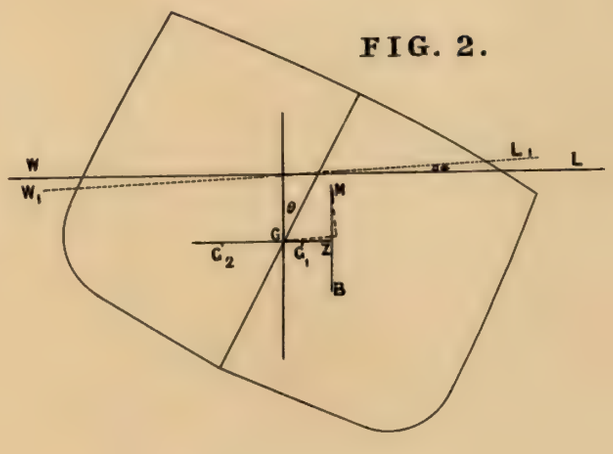
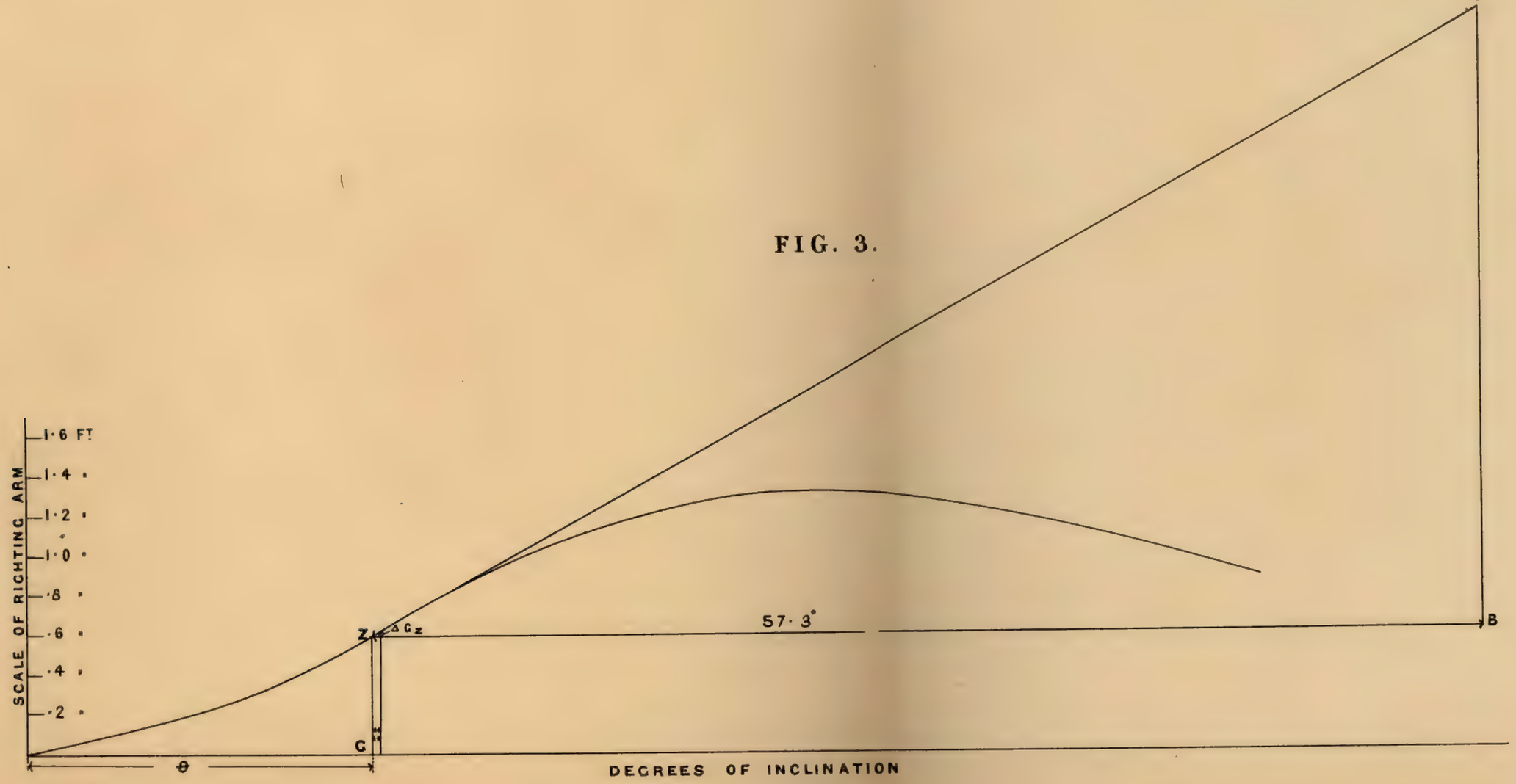


FIG. 3.



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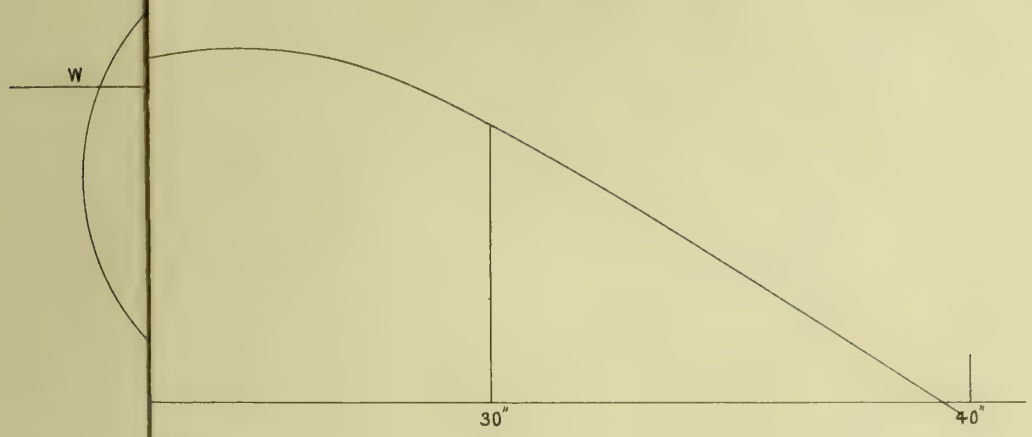


TION.

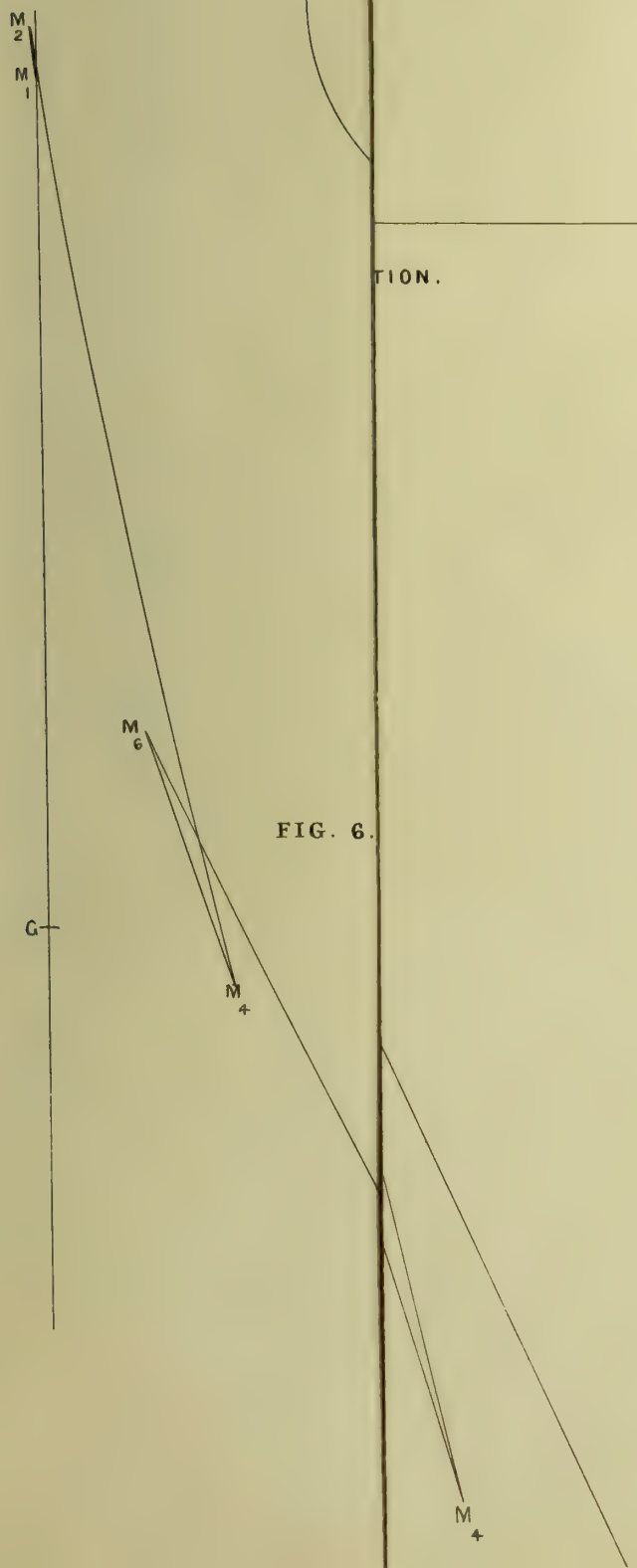


FIG. 6.

To Illustrate Professor P. Jenkins' Paper on the Connection between the Curve of Stability and the Metacentric Curve or Locus of Pro-Matacentres.

FIG. 4.

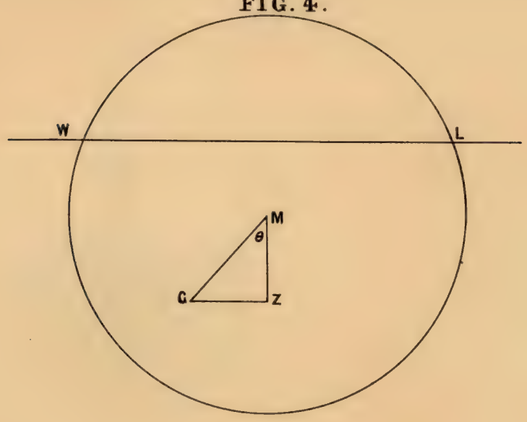
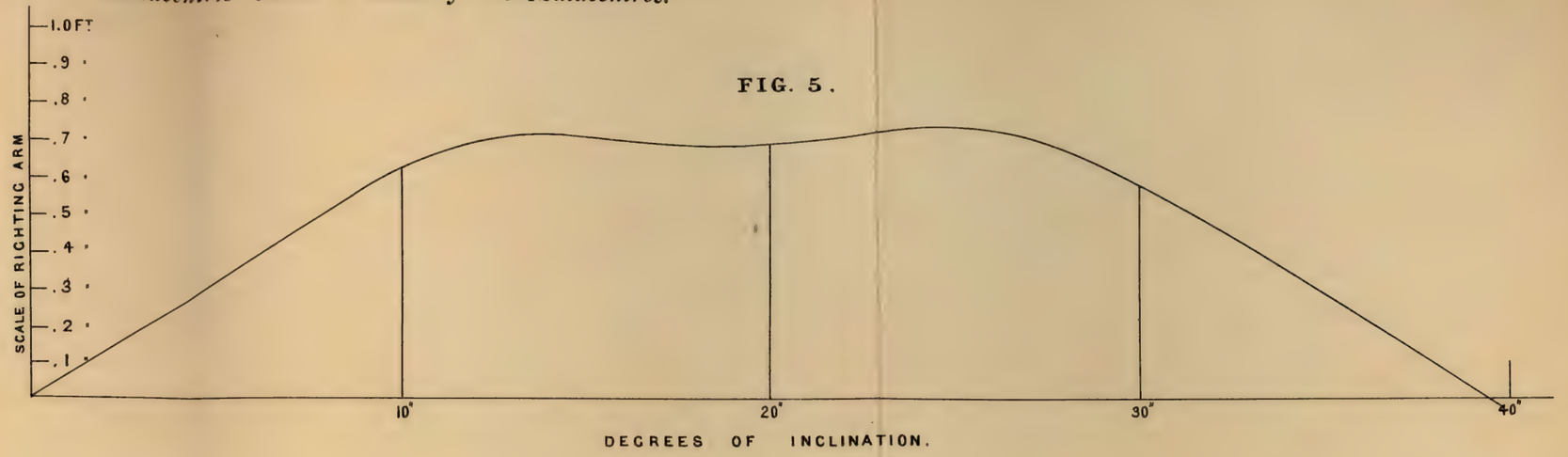


FIG. 5.



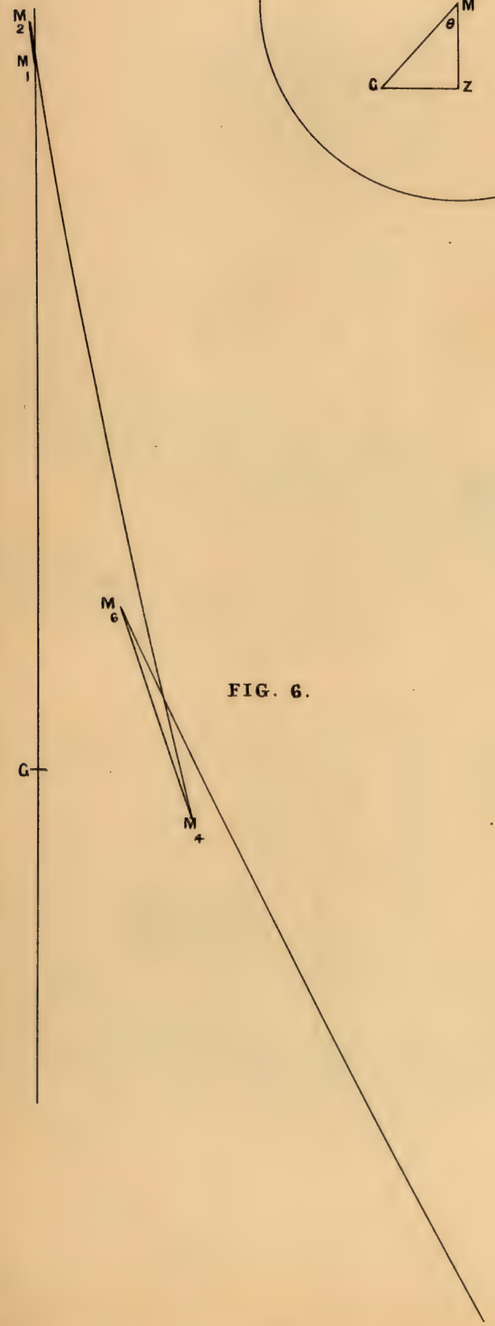


FIG. 6.

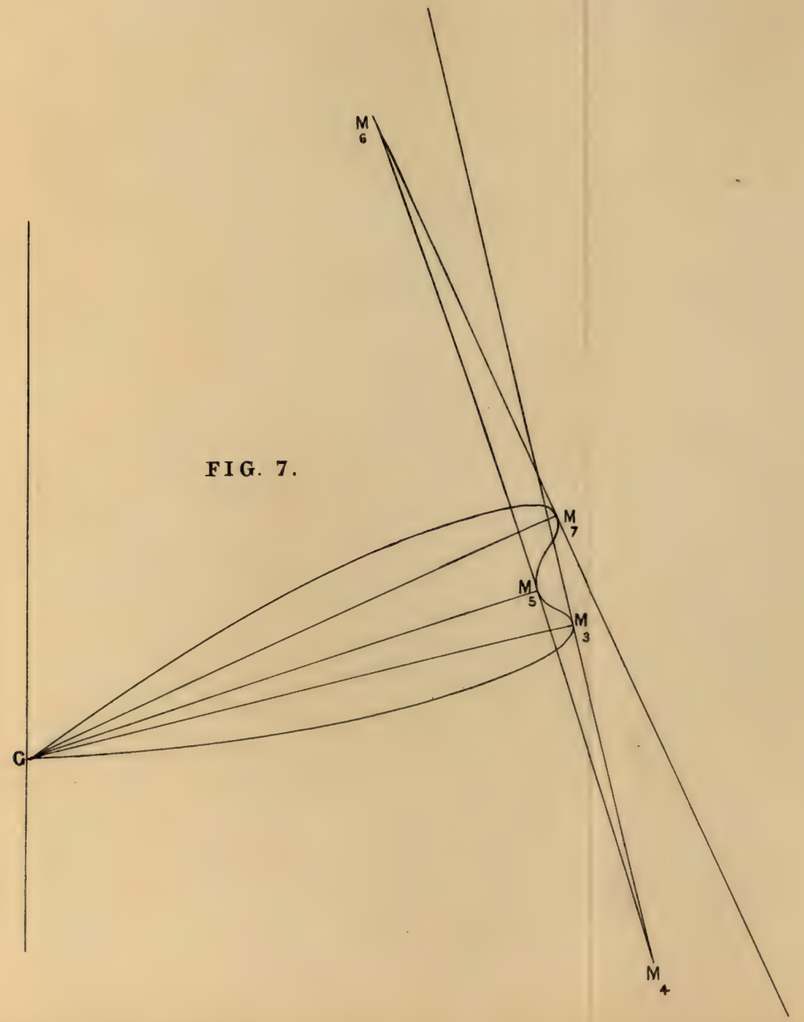
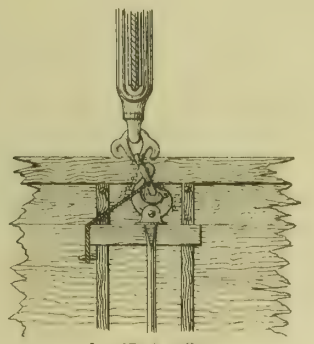


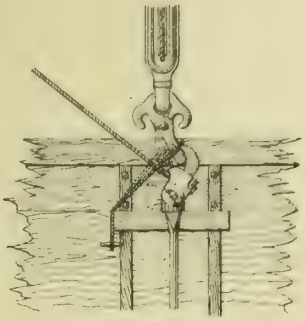
FIG. 7.

To Illustrate Mr. E. J. Hill's Paper on Boat Lowering and Disengaging.



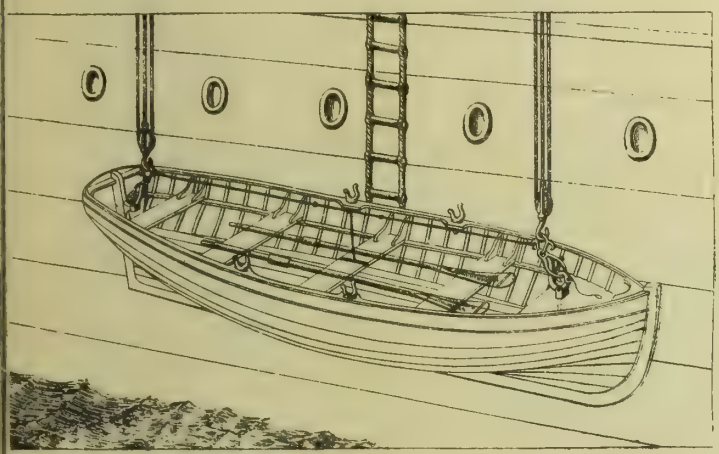
A. *Hook*, 1872.

FIG. 1.



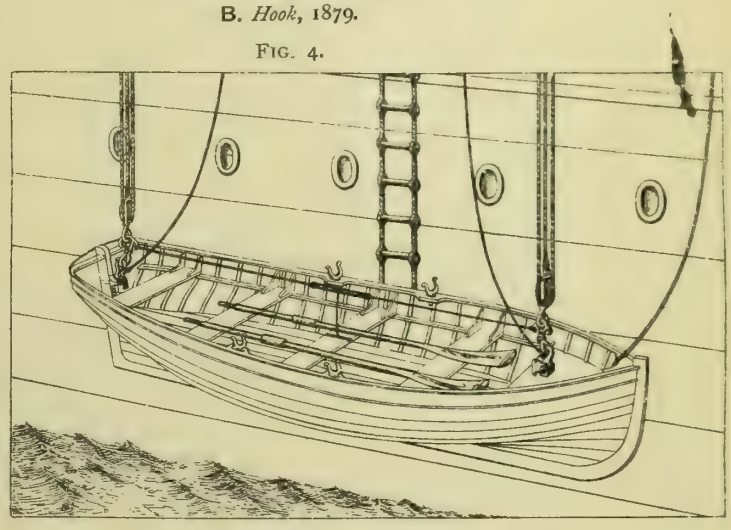
B. *Hook*, 1879.

FIG. 4.



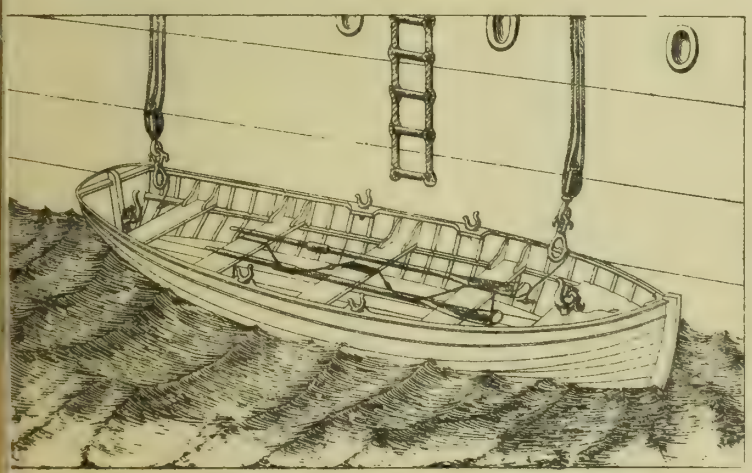
A. *Hook*, 1872; *Boat Hanging to Davits.*

FIG. 2.



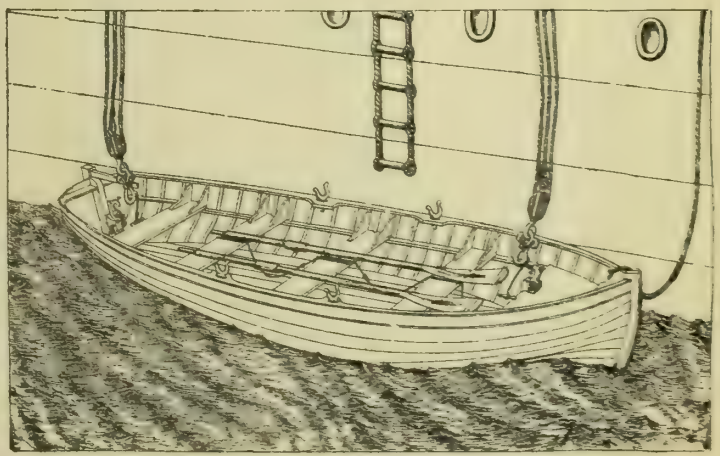
B. *Hook*, 1879; *Boat Hanging to Davits.*

FIG. 5.



A. *Hook*, 1872; *Boat Waterborne and Disengaged.*

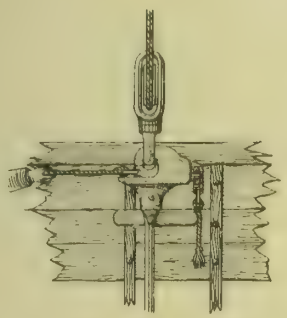
FIG. 3.



B. *Hook*, 1879; *Boat Waterborne and Disengaged.*

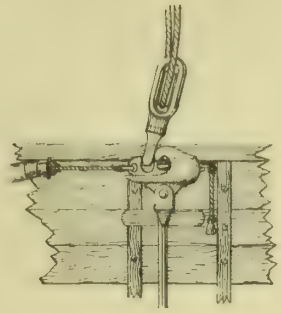
FIG 6.

To Illustrate Mr. E. J. Hill's Paper on Boat Lowering and Disengaging



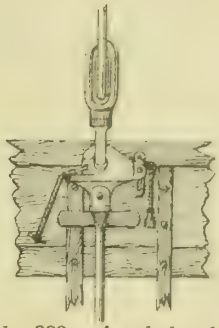
C. *Hook*, 1888; *Attached.*

FIG. 7.



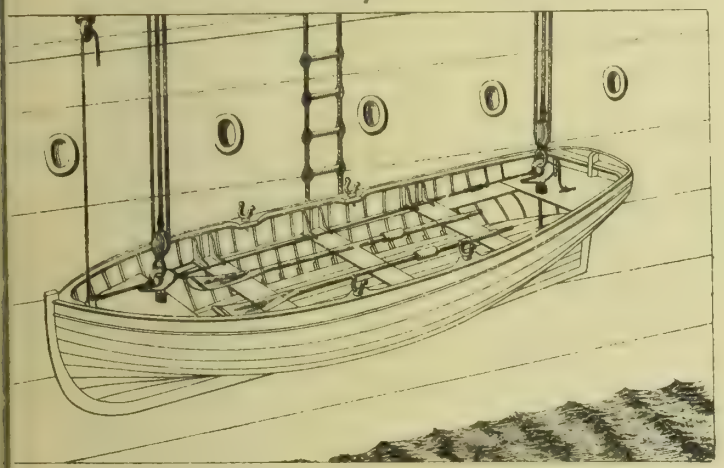
C. *Hook*, 1888; *Detached.*

FIG. 8.



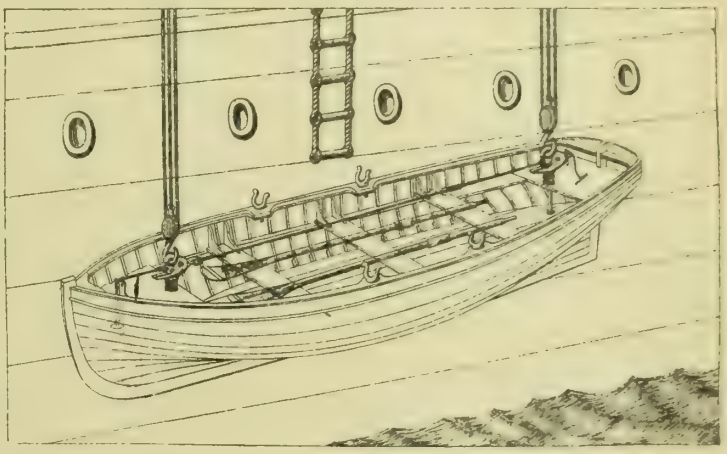
C. *Hook*, 1888; *Attached and Locked.*

FIG. 9.



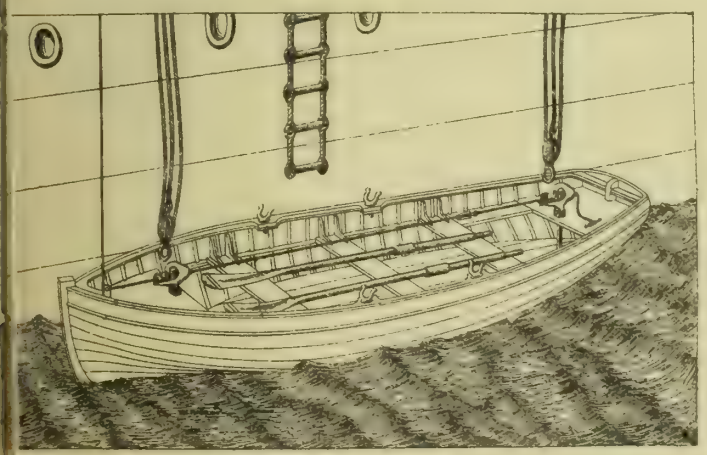
C. 1888. *New Hook, Attached. Fitted to be released by Painter, Boat Rope, Coxswain, or man on the Ship.*

FIG. 10.



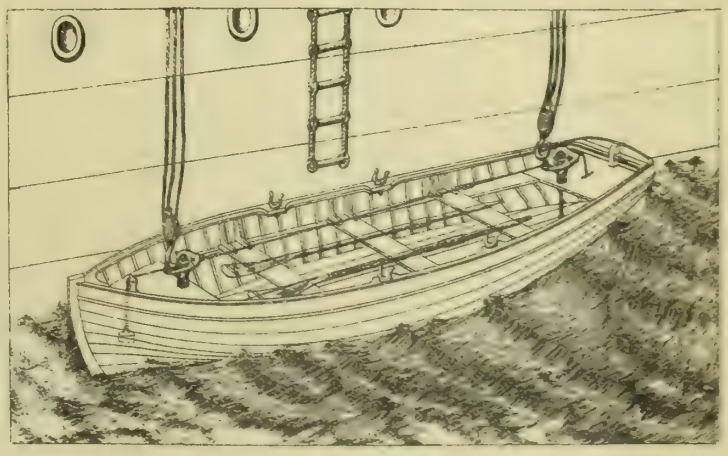
C. 1888. *New Hook, Attached. Fitted to work automatically.*

FIG. 12.



C. 1888. *New Hook. Released by the Painter, Boat Rope, Coxswain, or man on the Ship.*

FIG. 11.



C. 1888. *New Hook. Released automatically.*

FIG. 13.

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